ALTERNATE SITES FOR A CONNECTING PASSAGE BETWEEN THE ATLANTIC AND PACIFIC OCEANS

To the memory of my Father

ALTERNATE SITES FOR A CONNECTING PASSAGE BETWEEN THE ATLANTIC AND PACIFIC OCEANS

by

SAMUEL JOSE PEÑA, B.S.

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ABSTRACT

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SUPERVISING PROFESSOR: DR. ROY E. OLSON

The essence of this work is a geotechnical engineering report which includes a topographical profile at three propitious locations across the American continent for the construction of an interoceanic passage between the Atlantic and Pacific oceans. The surficial soils as well as the general topography of the centerline of the alignments were investigated to the extent possible. Also, an attempt was made at investigating the underlying strata. Some information is illustrated graphically, where possible, to allow an appreciation of the physical irregularities and a rough approximation for the type and extent of excavation required.

Although there exist various other alternatives, consideration is given here only to three locations. These are: in Mexico, across the Tehuantepec isthmus

and following the course of the Coatzacoalcos river as closely as possible; in Nicaragua, along its border with Costa Rica and using lake Nicaragua and the San Juan river as the main bodies of water; and in Colombia, in the vicinity of the Colombia-Panama border using the Atrato river as the main body of water. This study will not consider existing manmade obstructions for it is believed that a project of this magnitude will regulate all activities adjoining it.

The majority of the information was gathered from available geological reports and topographic maps. Some of the data for the Nicaraguan and Colombian routes was compared with information published in a study by the Atlantic-Pacific Interoceanic Canal Study Commission (1970).

Despite the fact that the Panama canal is restrictive to modern, large cargo vessels and that the locks system is expensive to operate and susceptible to malfunction or damage, little attention has been devoted to the field investigation of alternate routes. As a result, availability of useful data is scanty, especially in the remote areas of Nicaragua.

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INTRODUCTION

Ever since the discovery of the new world there had been a search for a connecting passage between the two oceans. Extensive efforts were made by Spanish voyagers during the first three decades of the sixteenth century to locate the elusive waterway and its search constituted the objective of Columbus's fourth and last voyage (Mack 1944). By 1530 the failure of countless persistent efforts to locate a natural strait had convinced most investigators that it did not exist in the tropical or temperate regions (Mack 1944). The southern tip of South America had been discovered by Magellan and found longer and more perilous than that round the Cape of Good Hope; exploration of the ice-bound seas and inhospitable shores of northern Canada proved so difficult that it proceeded with extreme slowness, and the tantalizing hope of finding a water route to the East Indies by way of the Northwest Passage was kept alive long after it had been abandoned in lower latitudes; the Northwest Passage, when found after a search lasting more than four centuries, proved to be

so long, so dangerous, and ice-free for so short a season of the year as to be practically useless as an interoceanic trade route (Mack 1944).

Thus was born the idea of an artificial canal to connect the two oceans. Credit for the first suggestion dates back to 1528 and is generally given to Alvaro de Saavedra de Ceron, kinsman and lieutenant of Hernando Cortes, and who had served with Vasco Nuñez de Balboa in Darien (eastern Panama) where he had had ample opportunity to note the extreme narrowness of the isthmus (Mack 1944). To this obscure reference there succeeded a long history of canal plans and proposals; however, not for another three hundred years, not until the nineteenth century, would a canal, even a very small canal, become a reasonable possibility (McCullough 1977).

The earliest authoritative study of the problem appeared in 1811 and designated Nicaragua as the route posing the fewest difficulties (McCullough 1977). The author of this rather tentative benediction was Alexander von Humboldt, the adventurous German-born naturalist and explorer (McCullough 1977). His nine recommended routes

included two in North America, three in Central America and four in South America. Unfortunately, he had built his theories wholly from hearsay, from old books and manuscripts, and the few pitiful maps then available, all of which he plainly acknowledged; Panama he judged to be the worst possible choice, primarily because of the mountains, which he took to be three times as high as they actually are (McCullough 1977). Between 1870 and 1875 the then President of the United States, Ulysses S. Grant, authorized seven naval expeditions-"practical investigations," he called them, to Central America (McCullough 1977) which provided accurate surveys of the various alternatives of interest at the time. The preferred locations and therefore those that drew the most attention were Panama (present canal location), Nicaragua, Darien (eastern Panama), Atrato (Colombia) and Tehuantepec (Mexico).

A sequence of financial, sentimental, political and technical events led to the ultimate decision by the United States to undertake the building of the canal in Panama after purchasing the rights from the French company which failed due mainly to their

insistence on a sea level design. The details leading to this final outcome are beyond the scope of this work. This historical introduction hopefully will serve to give a better impression of the quality and quantity of studies undertaken prior to the Panama canal construction. It is felt that during this period, a myriad of reports were generated in favor of any one of the contending locations and possibly all were tainted with some hidden interest that naturally proliferate within endeavors of this magnitude. After the Panama canal construction, rather cursory attention has been devoted to potential sites in other countries, whereas in-depth investigations have taken place in the vicinity of the present canal. Previous studies pertinent to the sites presented herein will be referenced as appropriate.

OBJECTIVE

The purpose of this work is to present soils information and topography of three corridors suitable for the construction of a connecting passage

between the Atlantic and Pacific oceans. The bulk of the data will be gathered from maps, previous studies and, where possible, from soil borings. It is anticipated that full representation of existing soil strata will not be possible due to the lack of recorded knowledge especially in the more remote portions of the study areas. The investigation is limited to three plausible locations for an interoceanic passage outside of the Republic of Panama. The exclusion of routes in the Republic of Panama is due to the belief that a second interoceanic route should and can be built outside of Panama simply because it is debatable that placing a second canal in Panamanian territory would be wise. The reasons are purely political since it is known that Panama offers the most advantages for a sea-level canal. One possible sea-level route in Panama, examined by the Atlantic-Pacific Interoceanic Canal Study Commission (Interoceanic Canal Studies, 1970), having similar characteristics to those discussed in this report, would require an excavation of approximately 2 billions of cubic yards. This alone represents a savings of about half the cost over the

most economical route presented herein. Further, the length of the route would be less because Panama offers the narrowest points between the Atlantic and Pacific oceans.

PROCEDURES

The soils-classification portion will rely mostly on previous studies and secondly on existing maps and soil borings. This order in the approach is simply because maps depicting soils information and soil borings are not readily available; however, the order of importance of data collection will be soil borings, existing maps and, lastly, previous studies. Overall, a correlation of all the available data will be established to come up with a result as accurate as possible. The presentation of the data will be textual as well as graphical where deemed appropriate to enhance the presentation.

Topographical information will be collected from existing maps of a suitable scale and transferred to create a profile view of the approximate centerline of the alignment.

SOILS CLASSIFICATION AND PROPERTIES

INTRODUCTION

In order to consider the various routes objectively, it is necessary to establish a set of basic criteria within the context of the subject presented herein. Pertinent criteria to be considered are the size and shape of the navigational prism and the minimum side slopes of the excavation to insure stability. The proposed configuration, for purposes of estimating quantities of excavation, would consist of a single-lane canal through most of the inland portions, provided with double-lane ocean approaches on both sides capable of allowing passing of ships in either direction. Inasmuch as the doubling of the width of the channel for the entire length to allow two-way traffic would raise construction costs prohibitively and exceed the future demands of capacity of transit as projected by the Atlantic-Pacific Interoceanic Canal Study Commission (Interoceanic Canal Studies, 1970), the selected configuration is a single-lane canal as stated earlier; considering the existence of the

Panama Canal this approach makes sense from the economical standpoint. If long-term future traffic demands were to require more capacity, a viable solution would be to extend inland the approach channels on either or both sides, following the least cost path, and thus shortening the single lane configuration which can then be restricted to the portion offering the greatest difficulty for widening. Based on extensive studies performed for the Atlantic-Pacific Interoceanic Canal Study Commission and practical experience gained in the operation of the Panama Canal (Interoceanic Canal Studies, 1970), the channel bottom should have a desired width of 550 ft and a centerline depth of 85 ft below and parallel to mean sea level; the ocean approaches could initially have a bottom width of 1000 ft and a similar depth as the inland channel with provision for future widening to 1400 ft if demands so require (Atlantic-Pacific Interoceanic Canal Study Commission, 1970). It should be noted that, for the design channel described as a single-lane above, vessels of 65,000-dwt or below could pass each other when transiting in opposite directions.

Also, the three alternate routes discussed here can be provided with passing lanes in the areas where the widening of the channel would involve dredging in soft formations; the Colombia route affords this opportunity in the swamps; the route through Nicaragua can be widened as such in the lake and in the impounded area of the San Juan river; and the Mexico route offers this opportunity on the Gulf of Mexico side with more than 80 km of alluvial deposits.

For purposes of information, the Panama Canal is limited by draft and lock size to transit ships up to approximately 65,000-dwt; ships that would be precluded from transiting the canal because of size are those that exceed 106 ft in beam and 950 ft in length; vessels in the transit draft range 36 to 40 ft are subject to draft restrictions (Atlantic-Pacific Interoceanic Canal Study Commission, 1970). However, exceptions to these limitations are possible; on 30 August 1984, the U.S. Navy Iowa-class battleship USS Iowa with a beam of 108.2 ft transited the Panama canal (Shaw, 1985).

The minimum slope criteria is one area where previous experience plays an important role and requires judicious application of engineering principles. Few projects have been accomplished in the recent past where the magnitude of excavation, the quality of soils, and where the local climatic conditions match those of the proposed routes. The Panama Canal has provided extensive knowledge in this area through bad experiences that have plagued the canal from the very beginning to as recent as 1985 when a massive slide interrupted normal operations; however, it is readily understood that the experiences of the Panama Canal, positive or negative as they may be, can hardly apply to other locations. Therefore, this remains an area where a common criteria is difficult if not impossible to come up with and perhaps the best approach is an extensive program of in-situ and laboratory testing of the materials complemented with perspicacious observations during construction. Based on a series of different routes and on the basis of laboratory tests and visual identification, materials encountered have been placed in five general

categories, with corresponding cross sections, by the Atlantic-Pacific Inter-oceanic Canal Study Commission; they are:

- -High quality rock (strong unaltered volcanic rock: basalts, agglomerates and tuffs);
- -Intermediate quality rock (strong sedimentary limestones and sandstones and some slightly altered volcanic rocks);
- -Low quality rock (silty and sandy claystones and altered tuffs);
- -Soft rock (clay shales and soft altered volcanic rocks); and,
- -Unconsolidated sediments (soft soils including Atlantic and Pacific mucks).

Figures 1 through 5 depict the excavation slope criteria for the above categories (Atlantic-Pacific Interoceanic Canal Study Commission, 1970). It is recognized that this classification lacks breadth and cannot possibly include all the different materials encountered in the three distinct areas under consideration, but that they can be useful as a starting point for estimating excavation quantities and for feasibility determination as long as work is

expected to be continuously evaluated by expert observations during construction. Of special interest is the 10(horizontal):1(vertical) slope shown on Fig. 5; this slope can be accommodated in the field to a steeper slope if the soils can stand it.

Classification of soils for engineering purposes is normal practice when in the course of a thorough investigation one tries to identify the various properties of different soils; this allows grouping of soils with related characteristics that are of importance to ascertain similarity of behavior in the field when subjected to artificial or natural loadings. The Unified System will be used to classify the soils in this report when enough information is available for such determination. Further, additional geological description will be provided when available for both soils and rock formations.

The information provided in this section will give an indication of the variation of the different formations and hopefully help in determining required excavation efforts. A rough calculation of excava-

tion requirements will be conducted based on the assumptions made throughout the text with respect to the expected quality of the soil or rock and using the different slope criteria discussed earlier. The reader is encouraged to arrive at his own conclusion regarding slope-stability characteristics for the excavation from the given soil descriptions and rock characteristics.

Data on tides is given for the three routes and is provided for purposes of information only.

It is recognized that the information provided herein should only be used as complementary or as a starting point for a more in depth and formal investigation which must include extensive field work that is clearly out of the scope of this study. With that in mind, it will be proceeded to cover the three different geographical areas that comprise the subject of this work.

COLOMBIA

The alignment contemplated starts on the Pacific side at Humboldt Bay, as shown on Fig. 6 and, after crossing the continental divide, quickly joins and

follows the course of the Truando river in a northeast direction to join the Atrato river, near La Honda, which it then follows to Candelaria Bay on the Atlantic. The scheme would be a sea-level canal connecting the Atlantic and Pacific oceans; the difference between the levels of these two oceans would induce currents that should be considered when dealing with ship maneuverability, but are judged tolerable (Atlantic-Pacific Interoceanic Canal Study Commission, 1970). Tides along the Atlantic side of this route range up to 1.1 ft, on the average, above and below MSL with an observed peak of 2.9 ft, while on the Pacific coast the range is up to 8.4 ft, on the average, above and below MSL with an observed peak of 14 ft (Atlantic-Pacific Interoceanic Canal Study Commission, 1970).

Starting on the Pacific side, a volcanic rock formation underlies the alignment shown for approximately 30 km. The dominant formation is the Choco volcanics, consisting mainly of submarine basaltic flows with some basaltic tuffs and agglomerates; these igneous rocks have been fractured and variably altered to produce substantial amounts

of montmorillonite; a series of faults were detected in the formation with their approximate location as depicted in Fig.7 (Atlantic-Pacific Interoceanic Canal Study Commission, 1970). Borings made in the vicinity of the alignment, on both sides of the continental divide, report a similar lithologic formation and confirm the presence of the faults. Some of these borings were drilled in excess of 380 m and found the basalts and tuffs intensely altered with zeolite and montmorillonite, highly fractured, and most fractures healed with calcite and zeolite; the compressive strength of these igneous rocks varied from 1,200 to 16,000 psi and their dry unit weight had a range from 132 to 176 pcf (Department of the Army, Jacksonville District, Corps of Engineers, November 1968).

Ground cover consists of fine-grained clayey soils varying in thickness from 6 to 14 m. The results of subsurface investigations for these residual overburden soils carried out during 1967-1968 report plasticity indexes ranging from 8 to an upper limit of 38 and liquid limits ranging from 41 to 80; they all plot below the A-line in the

plasticity chart and a general classification of MH-ML seems appropriate; the percent of fines smaller than 2μ ranges from 3 to 60%; finally, the shearing strengths of the overburden soils determined by means of Q-triaxial tests ranged from 0.25 to 1.35 tsf and the dry unit weight varied from 50 to 97 pcf (Department of the Army, Jacksonville District, Corps of Engineers, November 1968).

When considering the slope stability of this first leg of the route, two features are of concern; the first is the presence of the fractures reported above and secondly, the presence of basaltic tuffs altered with montmorillonite which will adversely affect the stability of slopes. In areas where either of these two major problems is present, it is likely that the excavated side slopes will dictate the use of the soft rock slope criteria shown in Fig. 4. Tight control in the relationship between field studies and proper slope criteria is essential to preclude the exorbitant costs associated with the shallower slopes. This cut through the continental divide with an approximate maximum depth of 300 m is one of the major undertakings of this route, the

second being the excavation through the swamps and provision of a diversion channel for the Atrato river both discussed later.

Clearly, no single slope criteria from those presented in Figs. 1 through 5 will apply and the range of values in strengths for the volcanic formation, from the available test results, all but confirm the unpredictability in behavior to be expected from the slopes. Notwithstanding this worst case scenario, it is probable that a sound formation exists below a reasonable elevation allowing the application of high quality rock slope criteria for the bottom of the channel. A great deal of information can be gained through observation of natural slopes and during the open pit quarrying normally employed for these massive excavation efforts; special attention should be directed to the observed difficulty of cutting, the observed stability of the open cuts and instances of raveling, if any, water table location and conditions at the bottom of the excavation. The soils testing program should be aware of the need to test at different orientations to detect any anisotropy and strength

variations. Additionally, a system to monitor the faults movements should be implemented. The importance of information gathering during construction and feedback to the field after meticulous analysis cannot be overstressed and should help preclude any major difficulty while minimizing the volume of excavated material.

Progressing along, we find that at about the 20 km mark on the alignment, there exists a pocket of layered sediments overlaying the volcanic rock formation named the Sautata group. A boring log in the immediate vicinity describes drilling to a depth of about 38 m through soft clay at which point a very porous amphibole felsite was encountered for about 26 m; below the felsite, some 120 m of soft claystone and soft siltstone were drilled with wood fragments and plant remains encountered; at around a depth of 180 m, a siltstone formation was encountered at which point severe caving of the boring occurred and attempts to stabilize the hole with cement were unsuccessful; the top half of the 120 m layer of claystone was found to have an unconfined compressive strength of 7.2 tsf without further data reported

below this depth (Department of the Army, Jacksonville District, Corps of Engineers, November 1968). The determination of the extent in both surface area and depth of this pocket of sediments is of utmost relevance; subsurface investigation should allow a complete mapping of this formation to address better the manner to handle its removal. The top soft clay could prove challenging for removal as well as disposal and the potential for slides could become severe during rainy periods or if the underlying claystone dips toward the open excavation. Consideration should be given to using the residual versus the peak strength for analysis. A careful geotechnical evaluation is mandatory to assess the need for retaining walls supported on the underlying volcanic rock formation and/or some sort of slope stabilization. Fortunately, it appears that the bottom of this formation coincides with the top of the wetted perimeter of the proposed channel, rendering an easier solution to the problem; nevertheless, this fact must be ascertained during the geotechnical appraisal. The soft rock slope criteria seems suitable for this formation.

The transition from the Choco volcanics to the adjacent geological formation, termed the Truando formation, occurs around the 30 km point on the alignment. Borings performed in the vicinity permit an approximate definition of the contact between the siltstones of the Truando formation and the basalt of the Choco formation as a gentle dip turning steeper after a depth of about 120 m and the Truando overlaying the Choco formation along the interface.

The Truando formation consists of a series of tuffaceous siltstones, sandstones and mudstones with some rocks in this zone capable of sustaining stable slopes in deep cuts (Atlantic-Pacific Interoceanic Canal Study, 1970). A boring performed at a site overlain by the next formation, the Rio Salado formation, describes the upper 60 m of the Truando formation as a moderately hard siltstone with some sand layers underlain by soft, friable, calcareous sandstone about 107 m thick; at the location of the boring, the ground cover was about 20 m thick and there were about 67 m of the Rio Salado formation overlying the Truando (Department of the Army, Jacksonville District, Corps of Engineers, November

1968). Areas of low to intermediate quality rock can be expected and not much difficulty should be experienced in attaining the corresponding slope criteria of Figs. 2 and 3 especially in cuts through sandstones where the intermediate quality rock criteria seems appropriate. Care should be exercised when siltstones and mudstones are encountered for these are expected to be softer than the sandstones.

Proceeding along the alignment, the geology changes once more from the Truando formation to the Rio Salado formation mentioned earlier, consisting of layers of soft claystone and mudstone having relatively low shear resistance (Atlantic-Pacific Interoceanic Canal Study Commission, 1970). The contact between the Truando and Rio Salado formations has again a gentle dip with the Rio Salado overlaying the Truando formation at the interface. The Rio Salado formation is primarily soft and moderately hard massive claystone, with a dry unit weight varying from 85 to 106 pcf and an unconfined compressive strength ranging from 2 to 43 tsf. The slaking propensity of this formation should be higher than the Truando formation and therefore due

attention is required with respect to slopes behavior when exposed to air and/or water. The soft rock slope criteria should prove satisfactory and further geotechnical investi-gation could substantiate the use of the low quality rock slope criteria for a lesser excavation effort.

The next change of geology occurs at about the 40km point and remains fairly constant for the remainder of the alignment. The alignment traverses the Atrato swamp with soils consisting of normally consolidated sediments. A boring drilled through the transition from the Rio Salado formation to the unconsolidated sediments reported 287 ft of soft estuarine clays with one clayey sand layer before encountering the Rio Salado formation which, at this point, consisted of conglomerate and moderately hard claystone (Department of the Army, Jacksonville District, Corps of Engineers, November 1968). Other borings drilled in the Atrato swamp to depths of 200 ft report soft silt and clay deposits containing organic material and some sand which have been grouped under the designation "Post-Miocene unconsolidated sediments"; the general classification

of these deposits is MH with a dry unit weight ranging from 36 to 79 pcf and an average unconfined compressive strength of 0.8 tsf (Department of the Army, Jacksonville District, Corps of Engineers, November 1968).

A series of borings made as part of the investigation of the Panamerican Highway describe the area around kilometer 115 of the alignment as having the top 8 to 11 m with a layer of highly plastic gray clay and silt with organics with an average N=1, underlain by fine to coarse gray sand with black zones with organics to around a depth of 17 m and having an average N ranging from 3 to 24 (Engineering Feasibility Studies, June 1966). These soft deposits represent the second major problem in this route; from the construction standpoint the concern is the maintenance of sufficiently flat slopes to prevent slides. As a minimum, the slope criteria given in Fig. 5 should be observed and adjusted if necessary after field observations. Another concern of importance is the provision of a diversion channel for the Atrato river; the main reason for this measure is to minimize silting of the channel by the

sediments carried by the river from the uplands causing a maintenance burden. The method of canal excavation in these soft deposits would be a combination of barge mounted draglines and hydraulic pipeline dredges; roads are non-existent and their construction would entail the construction of supporting embankments in stages with either sand drains or wick drains to reduce the time of consolidation of the normally consolidated deposits. Consolidation tests should be performed on these soils at reasonable intervals and at various depths to allow calculation of the approximate time required for this action. Consideration should also be given to the disposal site for the massive amount of spoil to be generated; close to the Atlantic shore the situation could be resolved rather easy by allocating an area in the ocean for such purpose without interference to canal transit operations; however, inland disposal could become a major issue due to the flatness of the terrain and the likely need of having to construct levees of sufficient height to contain the spoil even during periods of inundation. A

reconnaissance of the general area to this effect should be part of the initial planning process.

Slope stability problems are anticipated especially in the swampy deposits which occur in the portion lying below maximum elevation of 18m above MSL; the uppermost formation is generally incompetent and requires flat slopes for excavation (Department of the Army, Jacksonville District, Corps of Engineers, Oct.-Nov. 1967).

In general terms, the alignment starts on the Pacific with volcanics, transitions to siltstones and sandstones around kilometer 28; transitions again around kilometer 32 to claystones and around kilometer 40 gets into the Atrato swamp with normally consolidated sediments until it reaches the Atlantic at about kilometer 158 where the deltaic deposits may reach a thickness of 90 m. In the ocean approaches appropriate depth is reached within 4.8 km of the shore of the Atlantic side and 3.2 km on the Pacific; the Atlantic approach consists of sand and muck which would be excavated by hydraulic pipeline dredges while in the Pacific soft materials would be excavated by hopper dredges and rock would require

blasting and excavation by barge-mounted draglines (Atlantic-Pacific Interoceanic Canal Study Commission, 1970).

A calculation was performed to approximate the amount of excavation. An effort was made to incorporate the effects of the faults, fractures and alterations of the formations by varying the slope criteria throughout the alignment to fit the described irregularities. The high quality rock slope criterion was used beginning on the Pacific side; at kilometer 7 the low quality rock criterion was used; at kilometer 14, the high quality rock criterion; at kilometer 17, the intermediate quality rock criterion; at kilometer 20, the soft rock criterion; at kilometer 28.5, the intermediate quality rock criterion; at kilometer 30.5 the low quality rock criterion; at kilometer 35, the soft rock criterion; finally, from kilometer 40 to the Atlantic terminus the unconsolidated sediments slope criterion was used. The total excavation volume thus estimated was 4.67 billions of cubic yards.

NICARAGUA

This route has the distinct advantage of having in its path the largest body of fresh water, lake Nicaragua, existing between the great lakes in North America and lake Maracaibo in Venezuela, South America. Therefore, it seems practical to make use of this natural water bridge when in pursuit of a navigable connection between the Pacific and Atlantic oceans. It is undoubtedly a feature that should be exploited and represents the key reason for selecting this route as possibly successful. Its elevation above mean sea level is around 31 m making this a mandatory lock canal if one is to preclude draining the lake into the ocean; this fact was one of the contributing reasons why the French in 1881, under the leadership of de Lesseps, attempted the first interoceanic canal at Panama reasoning that Panama was the preferred location for a sea level canal and Nicaragua for a lock canal. In his "Souvenirs", as well as elsewhere, de Lesseps had expressed the opinion that "it was very clear the Nicaragua canal was the best of canals with locks, if one were compelled to adopt that system" (Colquhoun, 1895).

When in 1889, faced with the impracticability of a sea level canal, and after many vicissitudes the work at Panama came to and end, the attention focused again on Nicaragua as a formidable contender now on equal footing. The interests tilted again in favor of Panama and the rest is known history.

The contemplated route begins on the Pacific at about 4.2 km northwest from San Juan del Sur at the mouth of El Baston creek in Marcella bay as shown on Fig. 12. After crossing the continental divide which is about 5 km inland, the alignment joins the head of the San Antonio river following a straight path to the Las Lajas river which it follows to its mouth on Lake Nicaragua near the village of San Alejandro; this leg from the Pacific ocean to Lake Nicaragua is approximately 20 km long. The passage through the lake is approximately 112 km long and the alignment hits land again on the eastern side of the lake just south of the town of San Carlos. From here on the alignment follows the general trend of the meandering San Juan river with an almost straight line to kilometer 225 of the alignment and then turning northeast and crossing the flats north of the San

Juan to its terminus at kilometer 273 in the sandbars of the village San Juan del Norte in the Atlantic. Tides along the Atlantic side of this route range up to 0.7 ft, on the average, above and below MSL with an observed peak of 2.6 ft, while on the Pacific coast the range is up to 6.2 ft,on the average, above and below MSL with an observed peak of 9.7 ft (Atlantic-Pacific Interoceanic Canal Study Commission, 1970).

Following is a geologic description of the formations along the proposed route which could serve as a basis to conduct the extensive field and laboratory testing program that this endeavor requires. It is recognized that the information herein provided lacks the necessary detail for anything but to acquaint the reader with the collective geophysical environment around one possible canal route; however, care has been exercised to offer more than the obvious coupled with reasonable assumptions based on the available data. Beginning on the Pacific side, the alignment cuts through the flood plain of a small creek consisting of alluvial deposits that the stream erodes from the

Brito formation on which it starts and ends. The Brito formation spans a narrow strip about 5 km wide, at the location of the proposed canal route, and parallel to the adjoining formation making contact with it through a fault zone which runs along the interface of the two formations and forms a ridge at the approximate location of the continental divide (Final Technical Report, Vol. IV, The Geology of Western Nicaragua, 1972). The Brito formation consists of a sequence of tuffaceous sandstone, siltstone, shale, and calcareous sandstone underlain by a limestone bed varying in thickness from 4 to 15 m which in turn is underlain by the basal Brito conglomerate consisting of well rounded cobbles of limestone, sandstone, siltstone, and occasional volcanic rock fragments; the thickness of the Brito formation has been calculated by various researchers to be in excess of 2400 m (Final Technical Report, Vol. IV, The Geology of Western Nicaragua, 1972). The rocks comprising the Brito formation are very susceptible to erosion and, because of this, waves and longshore currents continually wear away the soft strata and maintain precipitous slopes throughout

much of the coastline except at the pocket beaches that line most of the resultant coves; also, due to the rapid erosion, the river valleys are filled with an excess of alluvium and detritus, which the streams are unable to carry to the sea, reaching an average thickness of 33 m upland and 13 m at the mouths (Final Technical Report, Vol. IV, The Geology of Western Nicaragua, 1972). Lacking better information on the stratigraphy of the Brito formation, it will be assumed that the overburden soil thickness is 20 m, and that sandstone comprises the remaining thickness of excavated material to approximately elevation -30 m; for purposes of quantities computation, the intermediate quality rock will be used. The location of the shale layer demands careful attention for the excavation sides will impose stresses through a plane that might be weak due to anisotropy. Also, if a slope stability analysis of the shale is required, consideration should be given to using the residual strength which seems to govern under conditions of large strains as those experienced on the sides of excavated cuts. Further, if the excavation is such that the shale is

exposed to the air, the occurrence of slides is almost certain due to the weakening resulting from expansion upon moisture absorption.

As stated earlier, at about the 5 km point on the alignment, there exists a fault contact between the Brito formation and the Rivas formation, the latter one extending into Lake Nicaragua. The Rivas formation consists mainly of interbedded tuffaceous shale, siltstone, graywacke sandstone, and conglomerate; an extensive colluvial deposit consisting of sands, silts, clays, and pyroclastic material overlays the Rivas formation in the valley around kilometer 10 to 15 of the alignment (Final Technical Report, Vol. IV, The Geology of Western Nicaragua, 1972). A set of locks capable of raising vessels to the 31 m above mean sea level to match the lake level is required along this initial stretch of the route. Without attempting to finalize a decision that must be considered at the appropriate moment and based on the existing experience at Panama, it appears that a three step lock could handle the lift. Its location, if one is to minimize excavation, should fall on the continental divide at

approximately 5 km from the ocean; however, due consideration should be given to the presence of a fault, mentioned earlier at this location, and others as depicted on Fig. 13. Aside from this, the description of the underlying formations fit the criteria for intermediate to high quality rock at reasonable depths thus promising competent foundation for the locks and reasonable slopes for the excavations except for the valleys overlain by colluvial deposits which are expected to be poorly graded and having a low angle of friction. A slope of 1:1 for the underlying rock and 2(horizontal):1(vertical) for the colluvial deposits is used for quantity estimation. Appropriate slopes can be better determined after close field observation and laboratory testing. The warnings stated earlier for the shale of the Brito formation apply here as well.

The bottom deposits of Lake Nicaragua consist of gray silt, clay particles of a waxy texture and organic mud; coarse sand-like quartz, volcanic glass and rock fragments are present on the bottom (Boletin del Servicio Geologico Nacional de Nicaragua, No. 5,

1961). Its only outlet, the San Juan river, was reported by Sheldon (1899) to run clear for many miles from its starting point at the lake and only after its confluence with the San Carlos river did it become full of sand and mud which the latter brings from the mountains in neighboring Costa Rica. The "Boletin del Servicio Geologico No. 5" (op.cit.) reports that the lake has a maximum depth of 150 to 200 ft around Ometepe island. The thickness of the lake bottom deposits and their exact profile are unknown and left for further field investigation, however, it will be assumed that a maximum water depth of 85 ft can be obtained with hydraulic pipeline dredges where necessary. For purposes of quantity estimation a side slope for the excavated channel through the bottom of the lake will be assumed to be 2.5(horizontal):1(vertical); at the canal entrances to the lake, the slope criteria will be as per Fig. 5, but with a maximum water depth of 85 ft.

The alignment hits land again at San Carlos on the southeast shore of Lake Nicaragua. For the next 26 km, about kilometer 158 on the alignment, the

canal traverses low lands subject to inundation and generally described in the Final Technical Report, Vol. IV. (op. cit.) as alluvial deposits with no further description of stratigraphy or thickness given. This area appears to be largely the result of a long depositional process and consisting of a combination of volcanic ashes, sand, silt and clays carried by the streams into the lake, and further transported here over long periods, that are believed to be in a moderately overconsolidated state. A thorough field investigation should be undertaken to obtain the soil profile and identify the depth of a firm stratum and the water table; a slope stability analysis taking into consideration the non-uniformities of the soils can then be performed to determine the safe excavation slope for this portion. For quantities of excavation calculation purposes, the slope criteria for unconsolidated sediments of Fig. 5 will be assumed but, again, to a depth of water of 85 ft.

The remainder of the alignment is through an area where the geological information is only presented in the map accompanying the Final Technical

Report, Vol. IV (op. cit.) since this is now eastern Nicaragua and the report deals specifically with the western part of the country. Accordingly, the geological descriptions will be brief and not as suitable as desired for a proper appreciation of the quality of the formations from the engineering standpoint. In any event, reasonable assumptions will be made based on the available information. Continuing along the alignment, from about kilometer 160 to 171 a volcanic rock formation termed the Coyol Group is traversed; this group consists of basaltic lavas and ignimbrites or firmly welded tuffs. This formation could possibly rate as high quality rock but without information on stratigraphy and engineering properties, the slope for intermediate quality rock will be assumed. The leg from kilometer 171 to around 173 is described as alluvial deposits which presumably result from the confluence in the immediate vicinity of three minor rivers into the San Juan river; similar treatment as for the area at the outlet of the lake should be accorded to this area; that is, the use of the slope criteria for unconsolidated sediments of Fig. 5. The need for

subsurface investigation is again stressed. From kilometer 173 to 183 the Coyol Group is again encountered; it appears that this is a continuation of the same formation described earlier only that the presence of the rivers has created a vast pocket of alluvial deposits. Subsurface investigation should ascertain that this is the case and also determine the profile of the deposits, and the depth to the volcanic rock formation of the Coyol Group. Once this information is available, a better analysis can be made to determine slope stability criteria, meanwhile previous assumptions made for the same materials will be adopted.

Next to the Coyol Group formation a sedimentary rock formation underlays the route to kilometer 240 named the Machuca formation consisting of limestone and graywacke; a pocket of pyroclastic deposits overlays the Machuca formation from kilometer 226 to 230. The importance of this portion of the route lies in the fact that it is in the Machuca formation that the installation of the locks appears most appropriate because it includes the hills of the eastern mountain range also known as the East Divide.

Extensive sub-surface investigation is mandatory in order to place the locks in areas free of faults and with suitable bedrock foundation to minimize subsurface settlements and while simultaneously considering the possibility of earthquakes. From the components of the formation it is initially estimated that it is a competent formation pending further field investigation that would allow the determination of, among other things, the location of the water table and its direction of flow, the location of existing or potential fractures or faults, and the configuration of the bedrock floor and its suitability as a foundation material. High quality rock slope criteria for purposes of computing excavation quantities will be used.

The next formation is again the volcanics of the Coyol Group extending to kilometer 265 and overlain from kilometer 249 to 255 with alluvial deposits again coinciding with confluent streams. Similar conditions to those mentioned earlier apply here as well as far as quality of the formation and the need for further subsurface investigation.

Finally from kilometer 265 to the Atlantic shore alluvial deposits cover the final stretch with a series of lagoons encountered along the route that were possibly ancient shorelines to the ocean; one major problem in this deltaic swamp is the continuous silting of the mouth of the San Juan river and the shifting sandbars. This together with the fact that these young, loose deposits are probably incompetent, create a requirement for extensive improvements and possible inland location of harbor facilities. The excavated slope criteria for unconsolidated sediments will be used for calculation of excavation.

The major features of this route are the construction of the locks, the impounding of the San Juan river and the harbor construction at both sides. Although limited geological information is available, indications are that aside from the deltaic swamp at the mouth of the San Juan river, the several faults in the formations and the pockets of alluvium described at various locations, the excavations will be through rather competent materials. As a result, the geotechnical problems that can be anticipated relate to the field of rock engineering, poor deltaic

and lacustrine soil deposits and surface and subsurface water. Of specific concern are the identified faults, and those yet to be detected, and their effect on the construction of the locks. It would be desirable to place the locks on sound sedimentary rock formations instead of on the volcanic rock formations which are prone to have more fractures and faults than the former purely due to the nature of their origins. Worthy of note is the fact that most faults are the result of earthquakes in this seismically active zone which in turn are related to some volcanic activity visible or not; therefore, it is a reasonable assumption that a correlation exists between the faults and earthquakes. The Final Technical Report, Vol. IV (op. cit.) in a map of seismic epicenters for Nicaragua shows a high incidence of seismic activity along the Pacific coast of Nicaragua, northwest of the proposed route; three epicenters are shown in the vicinity of the Brito formation northwest of the canal alignment. On the Atlantic side, only one epicenter is shown on the Coyol Group formation with

others located further south in neighboring Costa Rica.

The volcanic activity if another concern for this route. The closest active volcano, the Concepcion, is located on Ometepe island on Lake Nicaragua which is located approximately 17 km from the nearest point on the proposed route through the lake; the Final Technical Report, Vol. IV (op. cit.) indicates it has a constant cloud of steam and gas from summit crater with its most recent eruption during 1957 consisting of pyroclastic ejecta. A second volcano, the Maderas, shares the island with the Concepcion but it is considered inactive; its sides are covered by dense forests and coffee plantations (Incer, 1973).

Information regarding the depth of the locks is subject to further refinement depending on factors of economy and future trends of ship sizes, specifically their draft. The Atlantic-Pacific Interoceanic Canal Study Commission (op. cit.) specifies dimensions of 160 by 1450 by 65 ft for double-lane locks as being able to carry a 150,000-dwt tanker; since the excavated channel depth is 85 ft, an adjustment to

the depth of the locks from 65 to 85 ft could be made if so desired. For purposes of this study, 65 ft deep locks will be considered. On the Pacific side, the proposal is to provide a three lift system allowing a change of water elevation from MSL of the Pacific to +31 m corresponding to Lake Nicaragua water elevation. On the Atlantic side, in order to take advantage of the various high points along the route, two sets of locks located as shown on Figs. 17 and 18 is proposed; the first one located at around kilometer 210 would be a single lift lowering the water level from +31 m to +20 m; the second one located downstream at around kilometer 237 would have two lifts allowing a lowering of the water from +20 m to MSL of the Atlantic ocean.

A calculation was performed to approximate the amount of excavation. Changes were made, where appropriate, to the slope criteria shown on Figs. 1 through 5 to take into consideration the effects of various differences throughout the alignment that were thought necessary to fit the actual field conditions as described. Beginning on the Pacific ocean, a modified slope criterion for unconsolidated

sediments was used; the change consisted in using a maximum berm elevation of 85 ft since the bed of the stream is at about elevation 0 MSL. At kilometer 6, the intermediate quality rock criterion was used; at kilometer 12, the soft rock criterion was used; at kilometer 70, in the middle of the lake, the unconsolidated sediments criterion was used. Further inland, at kilometer 154, a modified soft rock criterion was used; the change consisted in using 1.5(horizontal):1(vertical) for the side of the wetted perimeter in lieu of the 1:1 slope given in Fig. 4. At kilometer 168.5, the intermediate quality slope criterion was used; at kilometer 171.5 the modified soft rock criterion just described for kilometer 154 was used. At kilometer 175, the intermediate quality rock criterion was used; through kilometer 236, the high quality rock criterion was used; finally, at kilometer 273, the unconsolidated sediments criterion was used. The total excavation was thus calculated to be 4.87 billions of cubic yards.

MEXICO

The area of consideration is the Tehuantepec

isthmus in the southeastern part of the country which takes an east-west direction making the orientation of the route from north to south. The isthmus spans a distance of approximately 220 km at its narrowest point between the Gulf of Mexico and the Pacific ocean. This route has one major advantage over the other options and that is the closeness to both coasts of the United States. The site enjoyed popularity in the early days of interoceanic canal planning, and was among those carefully examined by the United States naval surveys of 1870-5 (Mack, 1944). However, in 1876 the Interoceanic Canal Commission voted unanimously in favor of a Nicaragua canal in effect eliminating Tehuantepec as a potential canal site (Mack, 1944). Subsequently, several attempts were made to revive the project but the only construction ever undertaken was that of a railroad. The canal option, however, remains a possibility if nothing else because Mexico offers more advanced technology and could possibly offer better logistical support than other countries in Central America and, above all, they still have the route closest to the United States.

It is anticipated that a sea-level canal can be cut through the isthmus and it is toward this scheme that this report is aimed. The highest point recorded in the suggested alignment is 310 m and occurs through a zone that is estimated to be of high quality rock.

Starting on the Pacific side the proposed alignment starts at the opening into the Pacific ocean of Laguna Superior, a lagoon resembling an inner bay enclosed by a natural sandbar, located east of the port city of Salina Cruz, as shown on Fig. 19. It then proceeds across the lagoon to a point between the towns of Juchitan de Zaragoza and Union Hidalgo. From here the route points due north passing about 7 km east of the town of Matias Romero, then joining the headwaters of the Coatzacoalcos river and following its meandering course passing east of Minatitlan all the way to the Gulf of Mexico next to the city of Coatzacoalcos; the total length being approximately 242 km. Tides along the Pacific side of this route range up to 2 ft, on the average, above and below MSL with an observed peak of 4 ft; on the Gulf coast, the range is up to 0.75 ft, on the

average, above and below MSL with an observed peak of 2.6 ft.

Information necessary to allow a purely superficial study for the feasibility of the construction of an interoceanic canal is simply non-existent; since the decision of the Interoceanic Canal Commission in 1876 to favor Nicaragua and the subsequent construction of the Panama canal, the efforts to collect geological field data for the specific reason of an interoceanic canal construction have been nil. Most of the available geological information is geared to mining, agriculture and projects of lesser extent and the studies undertaken prior to 1900 do not provide much useful information since no subsurface investigation was performed to speak of. Those reports are limited to somewhat detailed topographic surveys which are, nowdays, of limited value since a lot of manmade changes have taken place. Even for the purposes of economic development through the exploitation of the existing resources the knowledge is incomplete with respect to geology, petrology, stratigraphy, tectonics, morphology of the natural mineral deposits as well as

the paragenetic phenomena that brought them into existence (Gonzalez Reyna, 1962). As a result, preparing a geotechnically oriented report relying on the available data is at best a difficult task. A lot of assumptions will be made with the hope that the reader will understand the necessity for an extensive program of field observation of natural slopes and detailed geological mapping, including drilling, as the first step.

The following geological information was obtained from geological maps (scale 1:250000) prepared by the Directorate of Geography of Mexico by photogrammetry with field verifications and dated 1983-84. Additionally, complementary geological information is provided from other sources that are referenced accordingly. Those maps describe the formation closest to the surface and below the overburden soils without providing information on the thickness of the described formation or those underlaying it.

Picking up the alignment at the opening in the sandbar described earlier, the geological maps offer no information for the soils at the bottom of the

lagoon from the sandbar clear to where the route touches land; however, they will be assumed to consist of normally consolidated lacustrine soils consisting mainly of clayey fine sands where the corresponding excavated slope criteria shown on Fig. 5 applies. At about kilometer 30, the alignment enters land and for the next 20 km cuts through quaternary alluvial soils resulting from the erosion of the pre-existing rocks; these soils are reported to be silty, clayey deposits with grains of quartz, feldspar and mica. The 1871 surveying expedition under Shufeldt reported "In making a canal-cut across the Pacific plain, sand, loam, and shell-marl will be encountered, and near the foot of the Sierra a belt of modern lime, quite soft and pliable, will be met with....This portion of the isthmus is arid, with a sandy soil very permeable to water" (Report of Explorations and Surveys for a Ship-canal Isthmus of Tehuantepec, Navy Department, 1871). It is believed that these deposits can be treated as sand due to their reported high permeability, notwithstanding their earlier description as silty, clayey deposits. Laboratory testing should clarify the properties of

these soils; although, it appears that they can behave as cohesionless soils and drained analyses would be appropriate. Lacking any further information on the water table location, index properties, and actual depth of a firm stratum, the excavated slope criteria used for quantities calculation will be a modified soft rock slope criteria where the side slopes of the wetted perimeter will be 2(horizontal):1(vertical) instead of the 1:1 shown on Fig. 4; the upper slope remains the same as shown.

The next 6 km are shown on the maps as a sedimentary rock formation consisting of limestones that includes the Nizanda-Lagunas group utilized for the fabrication of lime; underlying these limestones are deep igneous rocks. Since limestones are normally moderately strong rocks, an intermediate quality rock slope criteria, as shown on Fig. 2, will be used for excavation computations.

At kilometer 56 and through kilometer 93 of the alignment there is a sequence of sedimentary rocks named the Todos Santos formation; it is described in the maps as a sequence of sedimentary rocks

consisting in alternating sandstone, conglomeratic sandstones and reddish to brownish conglomerates. The sandstone has fine to coarse grains with fragments of metamorphic and volcanic rocks, quartz and flint. The conglomerates are formed with fragments of igneous rocks and quartz with diameters ranging from 2mm to 1cm with a degree of roundness from subround to well rounded. This formation is underlain, in a discontinuous pattern, by Paleozoic granitic rock formations; it is overlain by Cretaceous calcareous rocks (limestone). It is possible this formation rates the excavation criteria for high quality rock, shown on Fig. 1, which will be used for excavation quantity computation, however, field observation of old natural slopes to insure that evolution to a flatter slope is not in progress is considered prudent. Also, field observations to determine the development of drainage basins can aid in estimating the strength of the rock formations; more channels, deeper incision, and more extensive removal of material occur on the lower strength rocks and, vice versa, fewer channels, shallower incision, and more resistant masses are found on high strength

material (Anderson and Richards, eds, 1987). Slaking tests of the conglomerates are recommended to insure the cementing material is sound and not susceptible to weathering when exposed in the deep cuts. Of further concern are three faults depicted on the maps and located at approximately kilometers 68, 71 and 75 of the alignment.

From kilometer 93 to 98 of the alignment the geological map reports an intrusive igneous rock formation consisting of medium grain granite. These assurgent granites are reported by Gonzalez Reyna (op. cit.) as being of secondary importance in reference to the total surface because they are invariably surrounded and covered by younger rock formations and their outcropping is mainly due to erosion. It should be noted that for the purposes of this study, these outcrops are of primary importance because they give an indication of the nature of the underlying rock formations. In this case it would be reasonable to assume that the cut could be made using the excavated slope criteria for high quality rock.

Continuing along the alignment, from kilometer 98 to 101 there is a sedimentary rock formation of

fine to medium grained sandstone with interbedded layers of conglomerates and described as having considerable thickness; it is described as being part of the Filisola and Paraje Solo formations. A certain amount of alluvial deposits overlay this formation at the location of a small stream. Caution should be exercised with the conglomerates to insure they are made up of hard components and properly cemented; sandstones are normally competent and the excavated slope criteria for intermediate quality rock of Fig. 2 will be used for excavation computation.

The next two formations appear to be, as pointed out earlier, outcrops that the erosion has allowed to emerge since they are representatives of an older geological epoch. The first one starts around kilometer 101 and extends to kilometer 106; it is described as a random sequence of slates, schists, sandstones and dolomitized limestones belonging to the Zacatera Group. The sequence is affected by a low grade regional metamorphism becoming more calcareous towards the dome with a clear foliation and overturned folds. This short description tends

to point out that these old rocks might be excessively fractured which may cause toppling failures of the slopes due to the many discontinuities. Therefore, the slope criteria for low quality rock will be used as shown on Fig. 3. However, since every opportunity for minimizing excavation must be pursued, proper investigation is not only necessary but worthwhile. The next formation is again an outcrop of an older rock formation through the younger sandstone; it is described as a grey limestone with abundant veins of calcite and physical characteristics that make it fit for use as aggregate and conveniently termed the Caliza Sierra Madre formation. This formation extends to kilometer 110 and the excavated slope criteria for intermediate quality rock will be used as shown on Fig. 2.

From kilometer 110 to 115 the alignment encounters again the sandstone described from kilometer 98 to 101. Proceeding along, from kilometer 115 to 130 a metamorphic rock formation consisting of a quartz-muscovite-biotite-chlorite schist banded with gneiss is described in the maps;

it is defined as the Sierra Mazateca formation. This formation is believed to be competent enough to rate the slope criteria for high quality rock.

The next formation extends to kilometer 146 and is similar to the one described for the interval from 98 to 101km.

From kilometer 146 to the end of the alignment in the Gulf of Mexico, the route traverses normally consolidated to slightly consolidated alluvial soil deposits consisting of gravels, sands, silts and clays that fill the fluvial valley of the Coatzacoalcos river. A portion around a large bend of the river crosses a leg from kilometer 158 to 164 consisting of a sandstone formation, as the one described from kilometer 98 to 101, which has preponderance in the northern half of the isthmus. Some portions of the alignment through the river valley are described in the maps as being marshy with a predominance of normally consolidated clays, silts and fine sands thinly stratified that contain abundant organic matter and are subject to inundation. The excavated slope criteria for unconsolidated sediments shown on Fig. 5 will be used

throughout for purposes of excavation computations. However, it must be stressed that the appropriate slopes must be determined after extensive scrutiny of a number of factors including, but not limited to, seismic, tidal, and climatic conditions of the area.

Since these areas are fairly built-up, it is believed that extensive local experience is available and can be obtained as background information and to calibrate the results of sampling and analysis used for design. The long term stability of the slopes is the most important concern of this project and its final outcome must be the result of a comprehensive testing program that must include local experience, close observation during construction and extensive monitoring during and after construction to ascertain the expected long term performance.

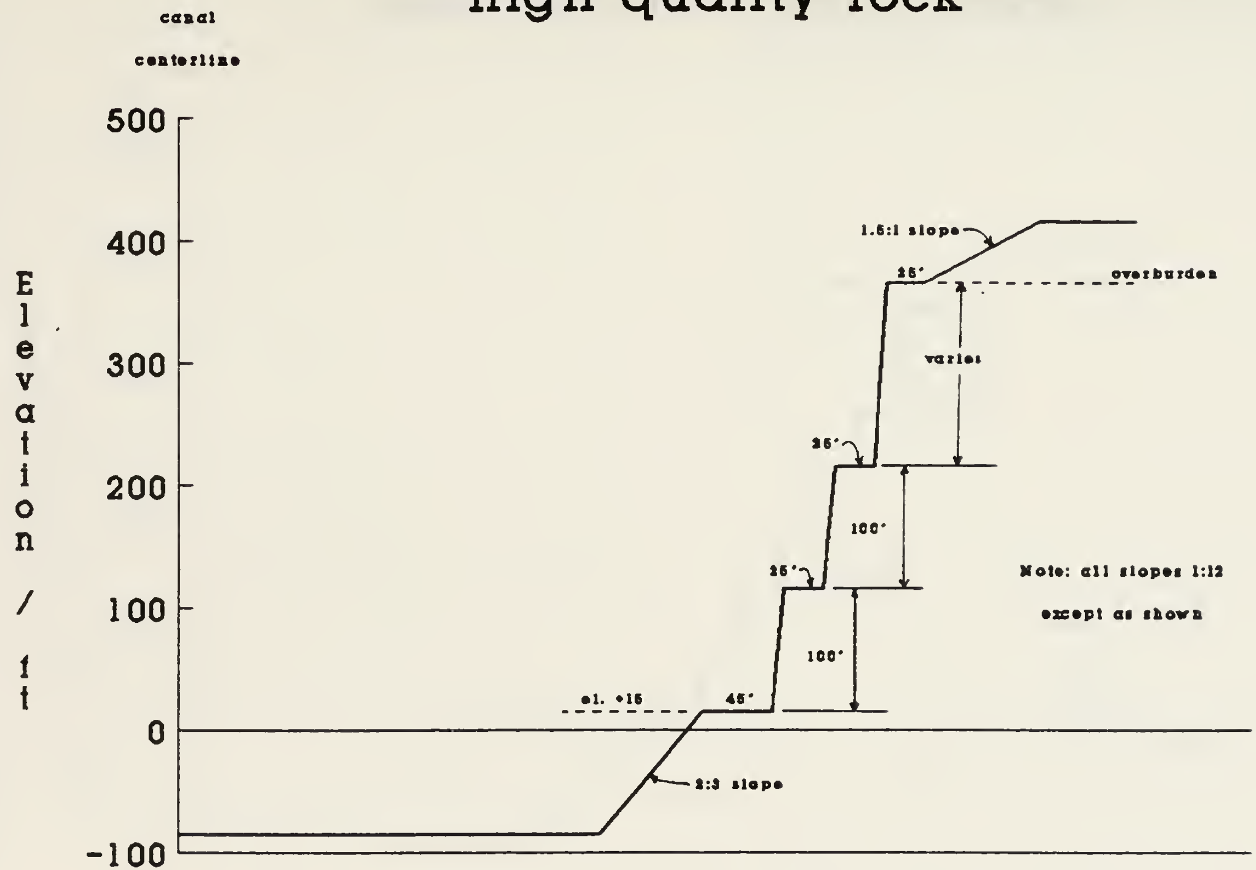
In general, this proposed interoceanic canal through the isthmus of Tehuantepec presents a formidable challenge in the deep excavation through the igneous rock formations of the continental divide. Also of importance is the excavation through approximately 95 km of alluvial deposits surrounding the Coatzacoalcos river, which may require

construction of a diversion channel to handle the volume of flow without interference with the canal transit. Of no less importance is also the amount of improvements that would be disrupted by this enterprise causing massive relocation of facilities which may include ports, railroads, roads, etc.

A calculation was also performed for this route to approximate the amount of excavation. Only one change was made to the slope criteria shown on Fig. 4 in order to use it for the cohesionless soil that underlies the alignment from approximately kilometer 30 to 49; the change consisted in varying the side slope of the wetted perimeter from the 1:1 shown on Fig. 4 to 2(horizontal):1(vertical). Beginning on the Pacific side, the slope criterion for unconsolidated sediments was used. At kilometer 46.2, the modified soft rock criterion mentioned above was used; at kilometer 54 the intermediate rock quality criterion was used. Through the continental divide, at kilometer 66.1, the high quality rock criterion was used; at kilometer 80, another cross section was taken using the high quality rock criterion, and again at kilometer 97. Further along,

at kilometer 100, the intermediate rock quality criterion was used, changing to the low quality criterion for a cross section at kilometer 104.5. At kilometer 115, the intermediate rock quality criterion was used; at kilometer 119, the high quality rock criterion was used, returning to the intermediate quality rock criterion at kilometer 133.5, and again at kilometer 139. The first cross section for unconsolidated sediments on the gulf side was taken at kilometer 150, changing to the intermediate quality rock criterion at kilometer 165 and reaching the gulf with a last cross section at kilometer 242 using the unconsolidated sediments criterion. The total excavation was thus calculated to be 9.44 billions of cubic yards.

Excavated slope criteria for high quality rock



Source: Atlantic-Pacific Interoceanic Canal Study Commission

Fig. 1

Excavated slope criteria for intermediate quality rock

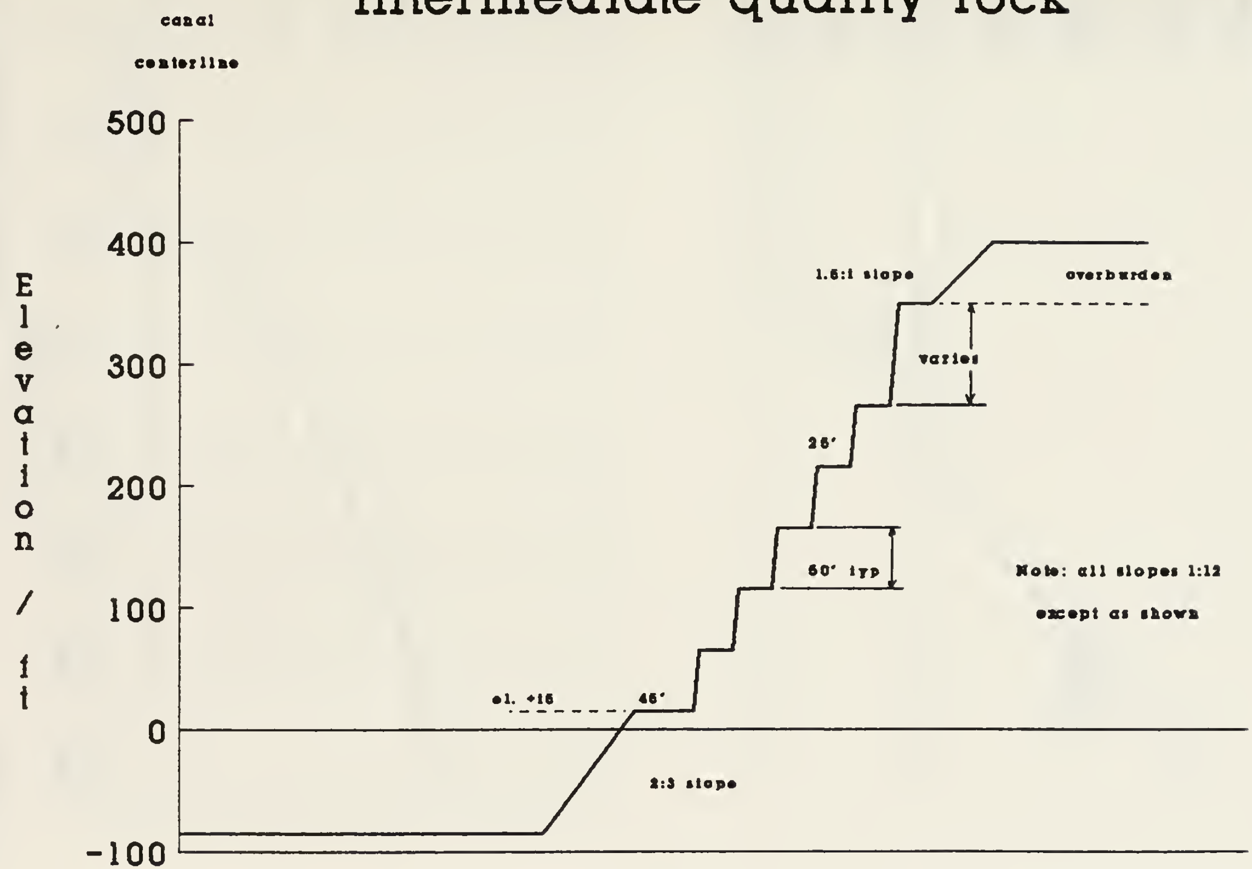
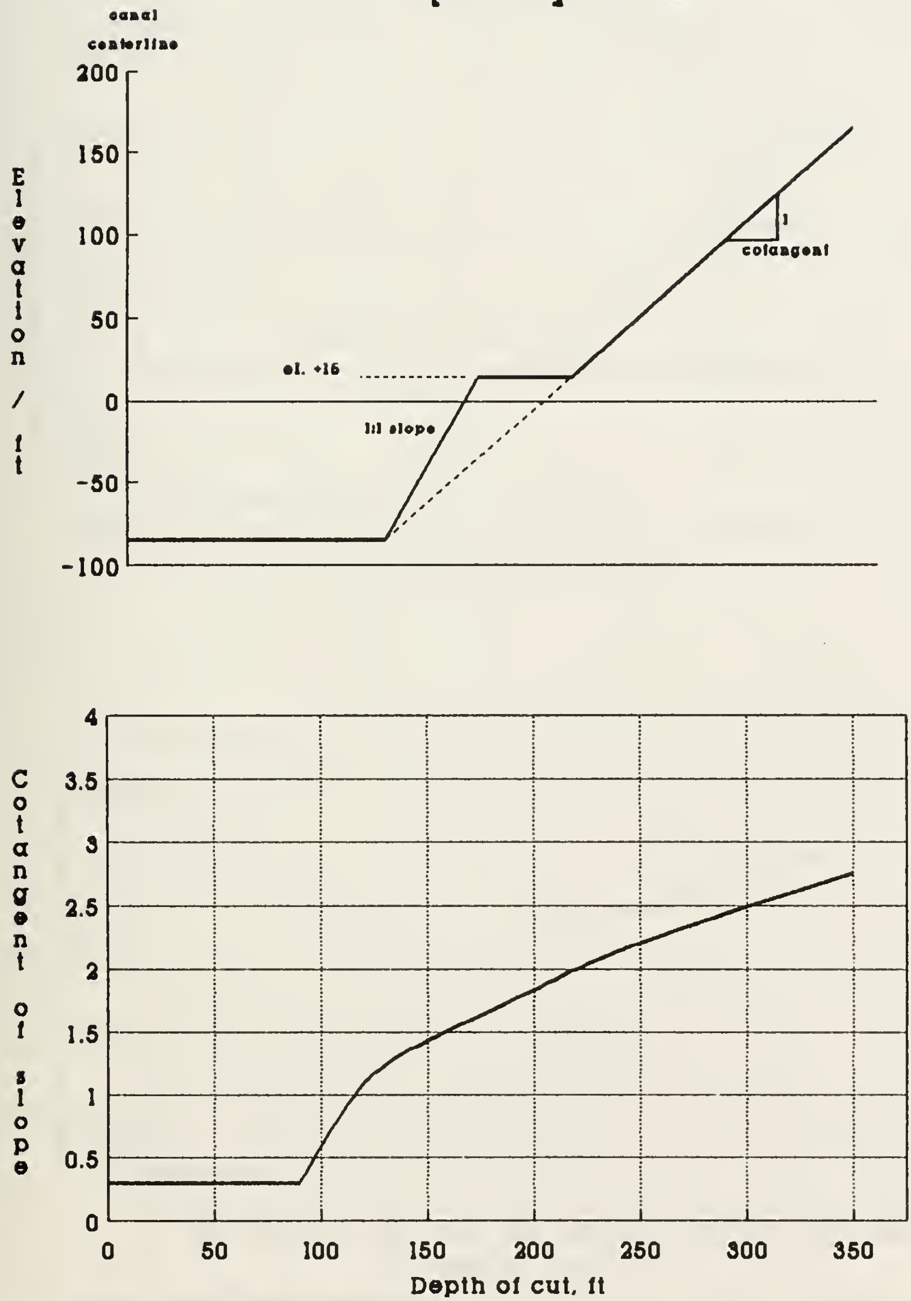


Fig. 2

Source: Atlantic-Pacific Interoceanic Canal Study Commission

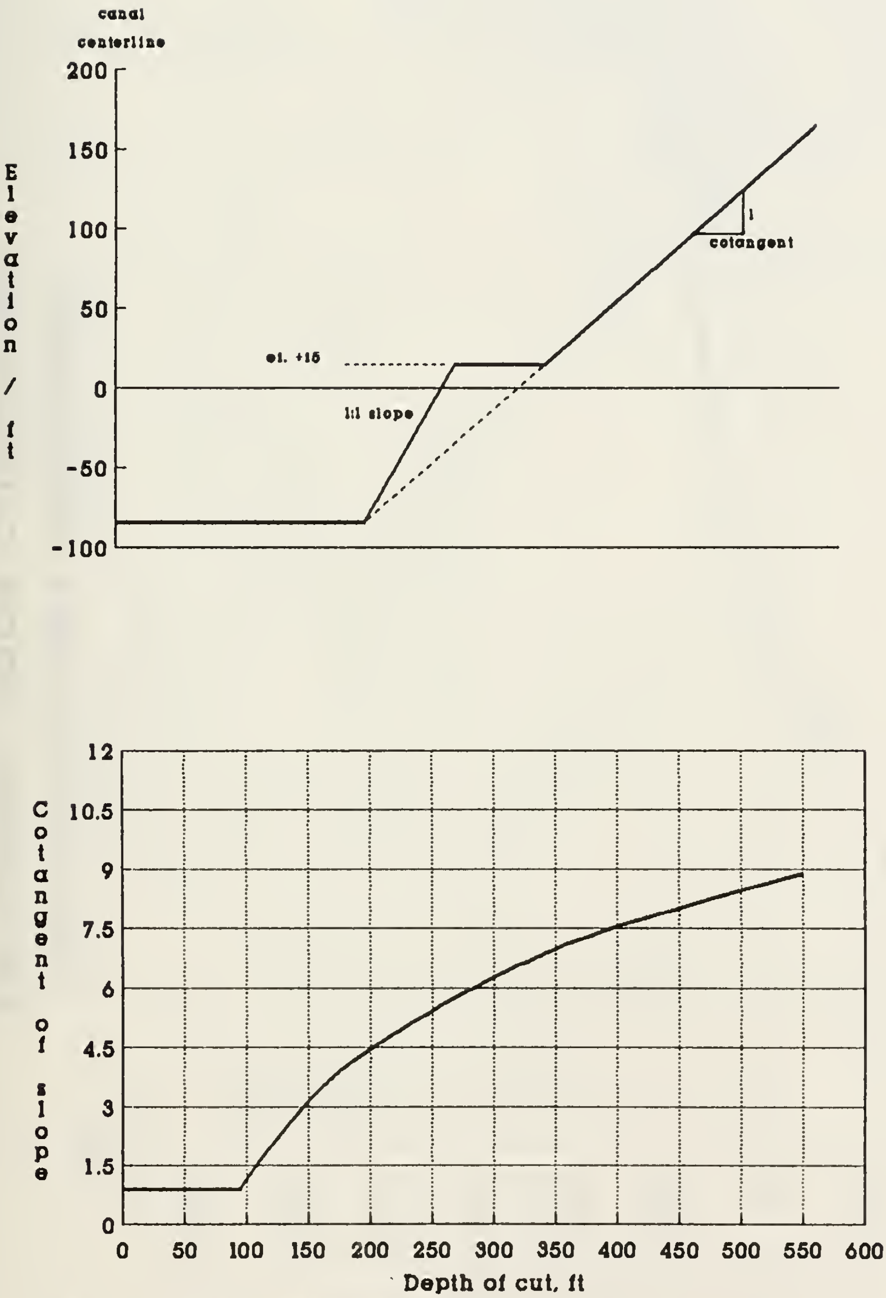
Excavated slope criteria for low quality rock



Source: Atlantic-Pacific Interoceanic Canal Study Commission

Fig. 3

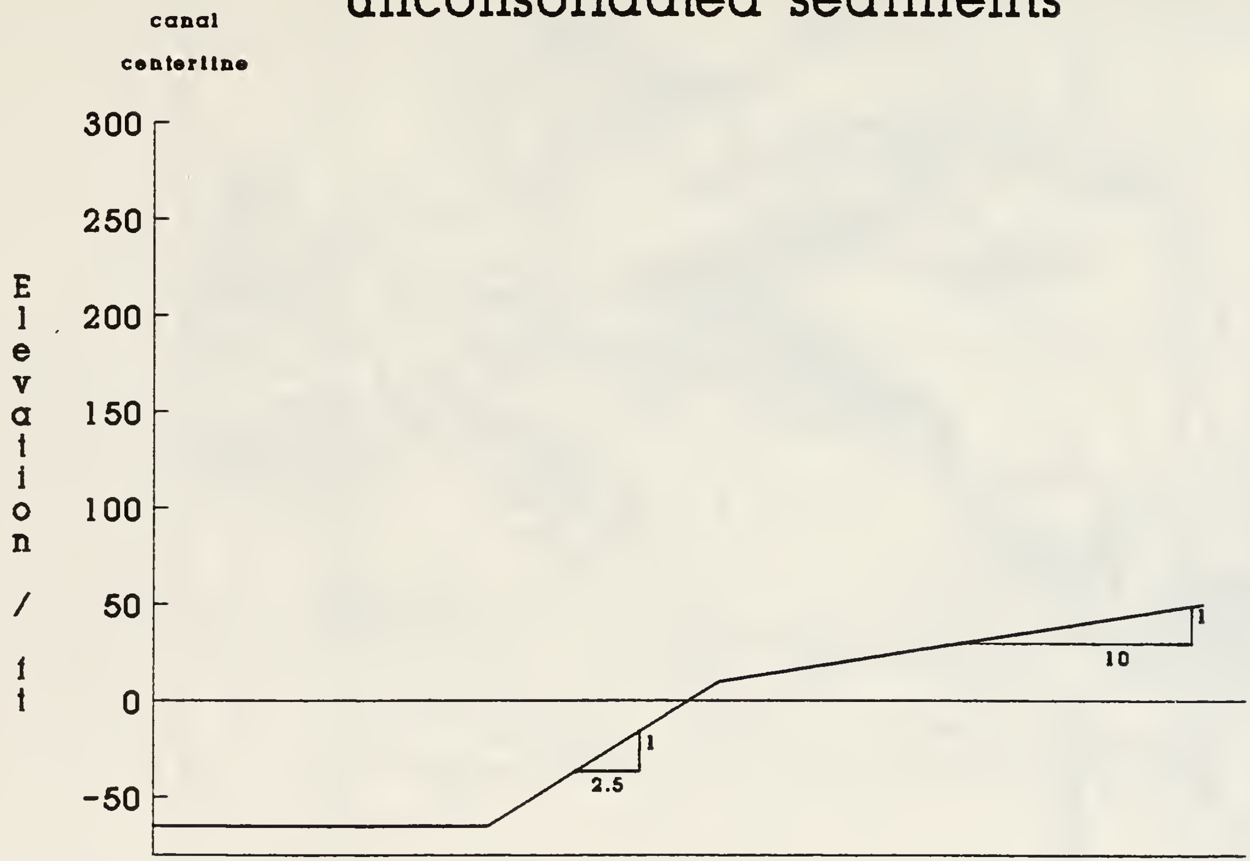
Excavated slope criteria for soft rock



Source: Atlantic-Pacific Interoceanic Canal Study Commission

Fig. 4

Excavated slope criteria for unconsolidated sediments



Source: Atlantic-Pacific Interoceanic Canal Study Commission

Fig. 5

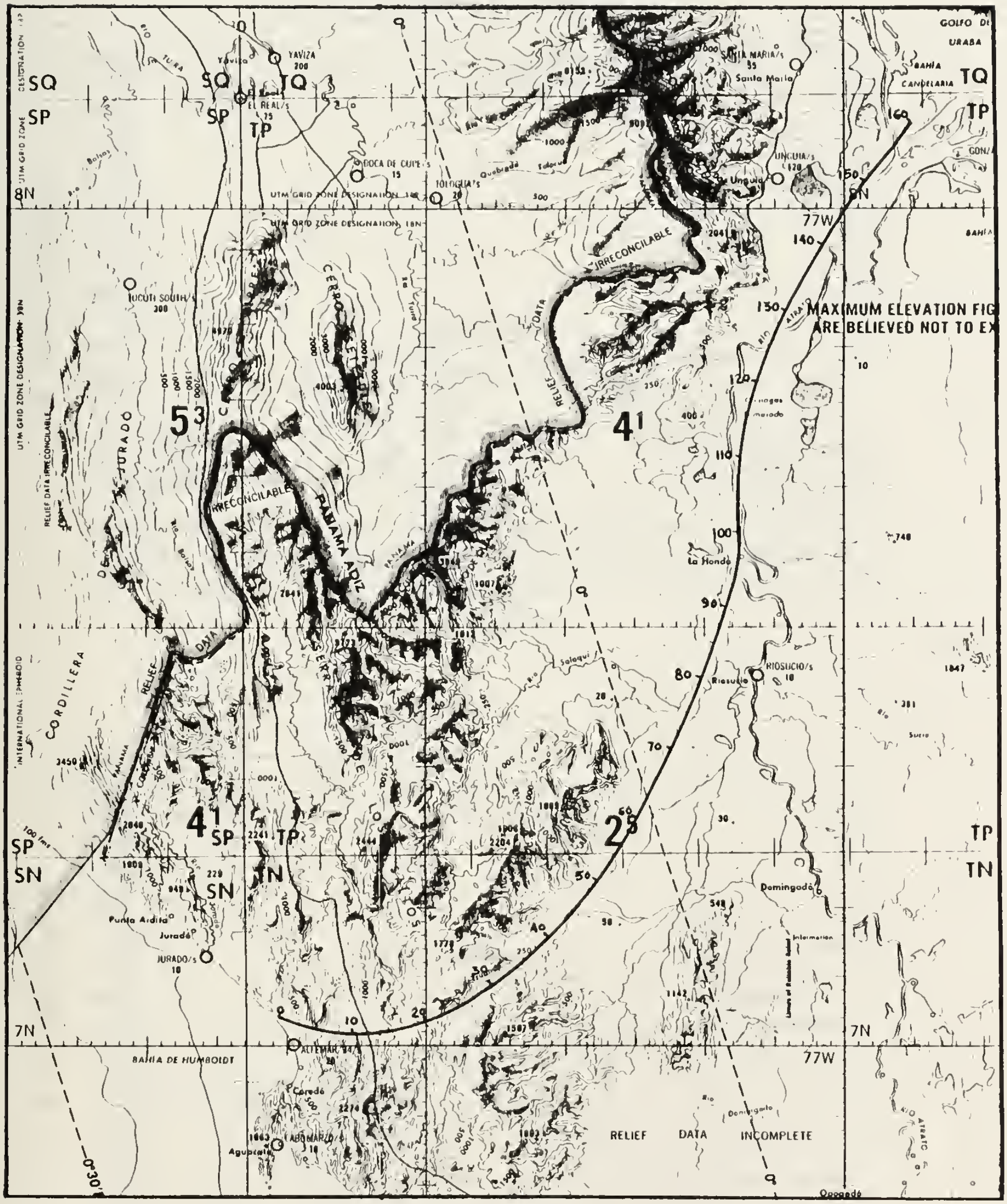


Fig. 6 Colombia route

Colombia profile

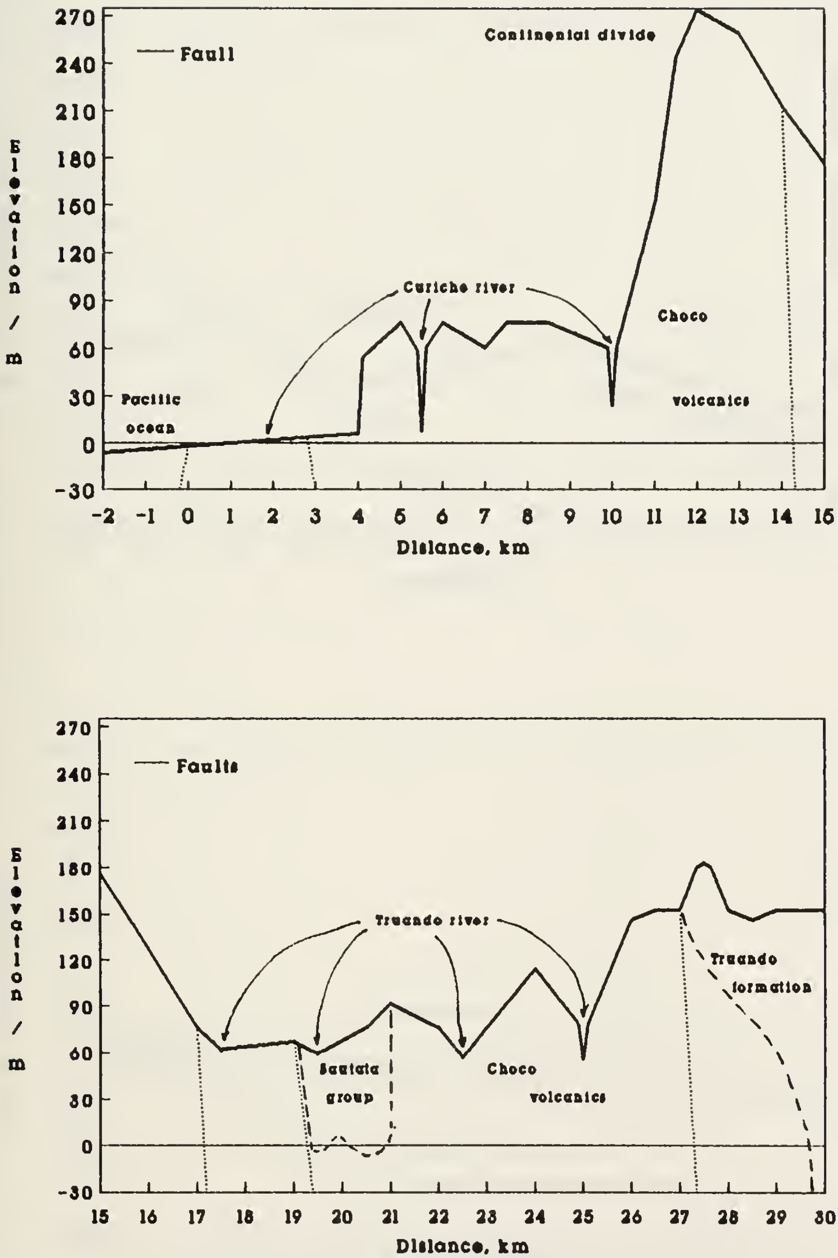
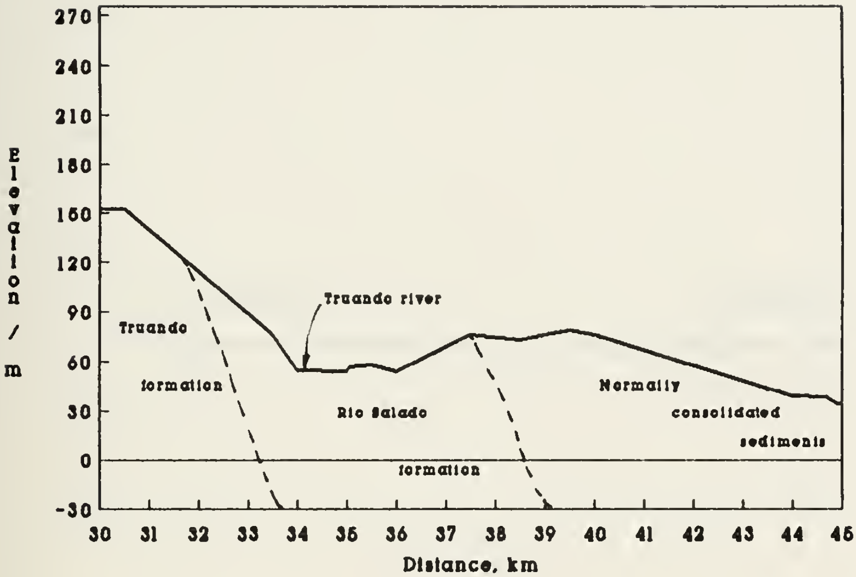


Fig. 7

Colombia profile



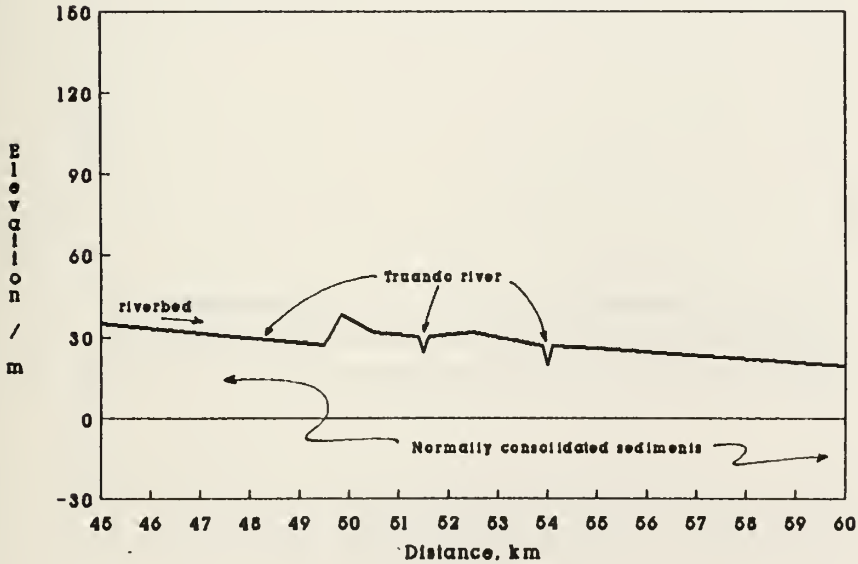


Fig. 8

Colombia profile

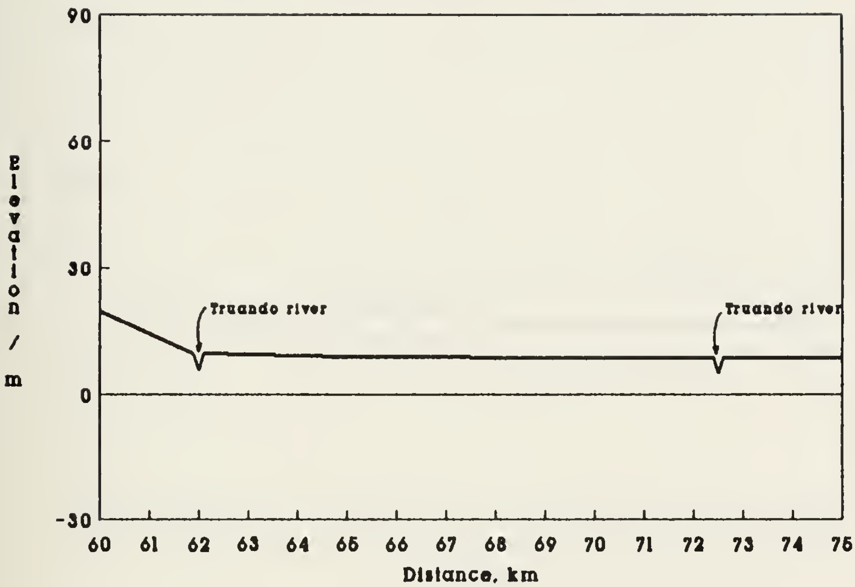
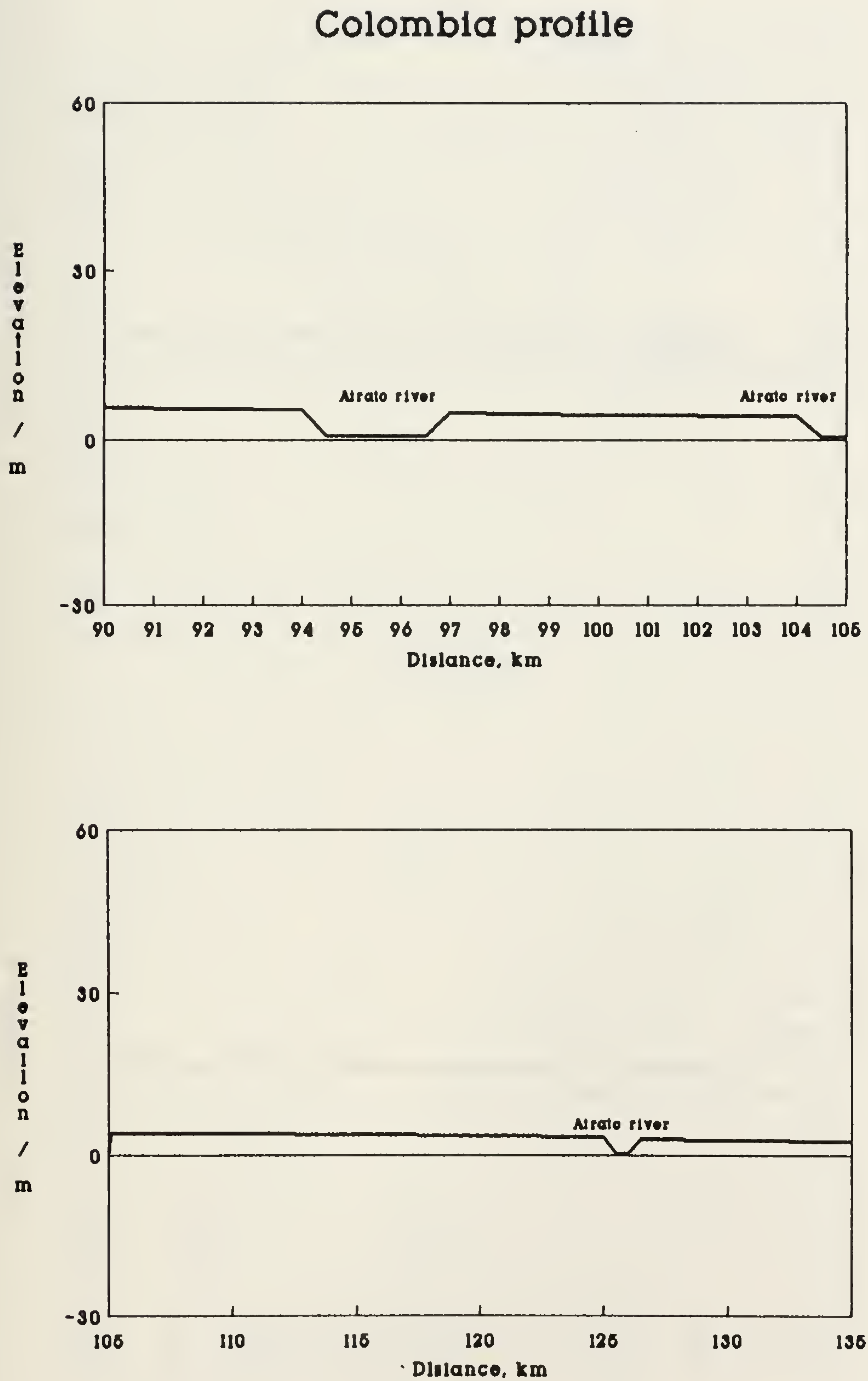


Fig. 9



Colombia profile
60
30
0
-30
Elevation / m
Atrato river
Atrato river
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
Distance, km
60
30
0
-30
Elevation / m
Atrato river
105
110
115
120
125
130
135
Distance, km

Fig. 10

Colombia profile

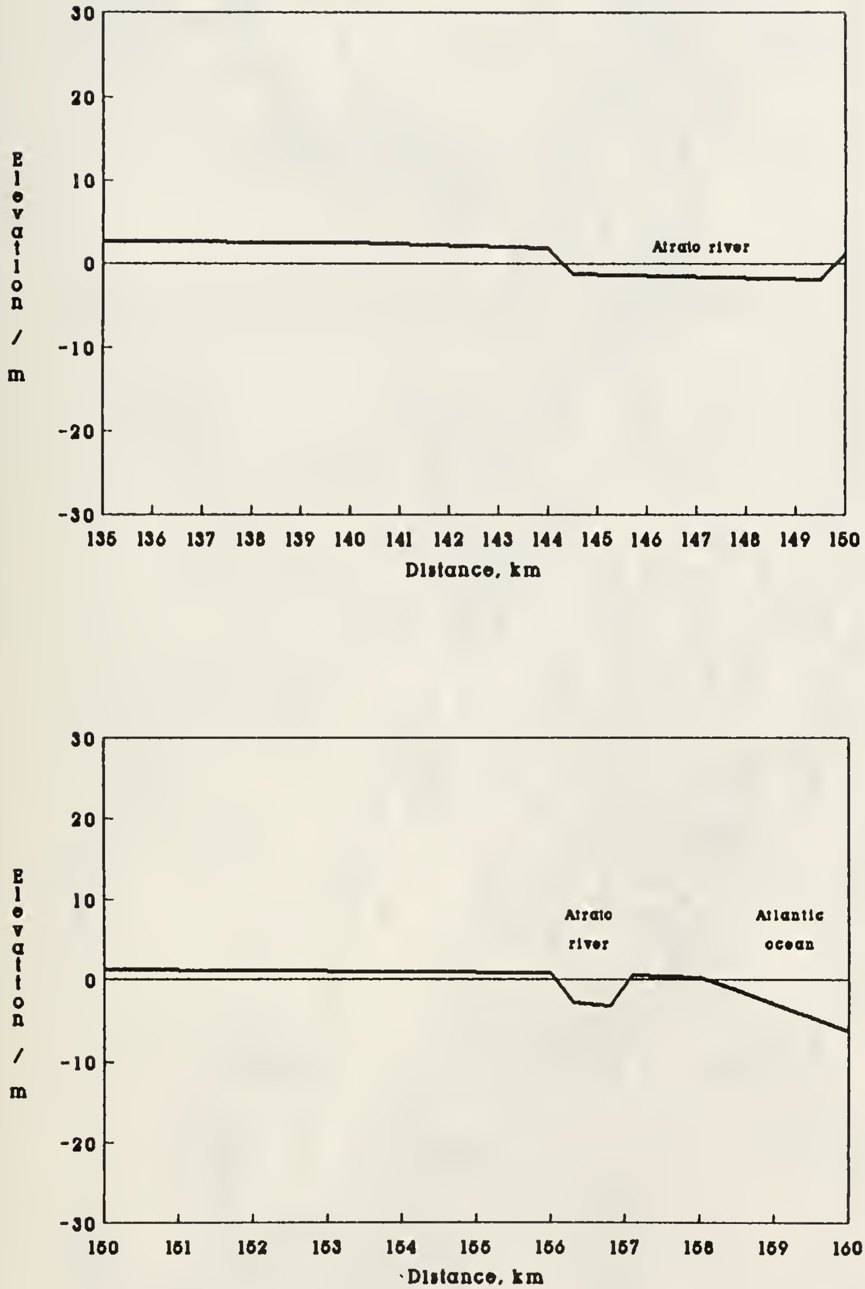


Fig. 11

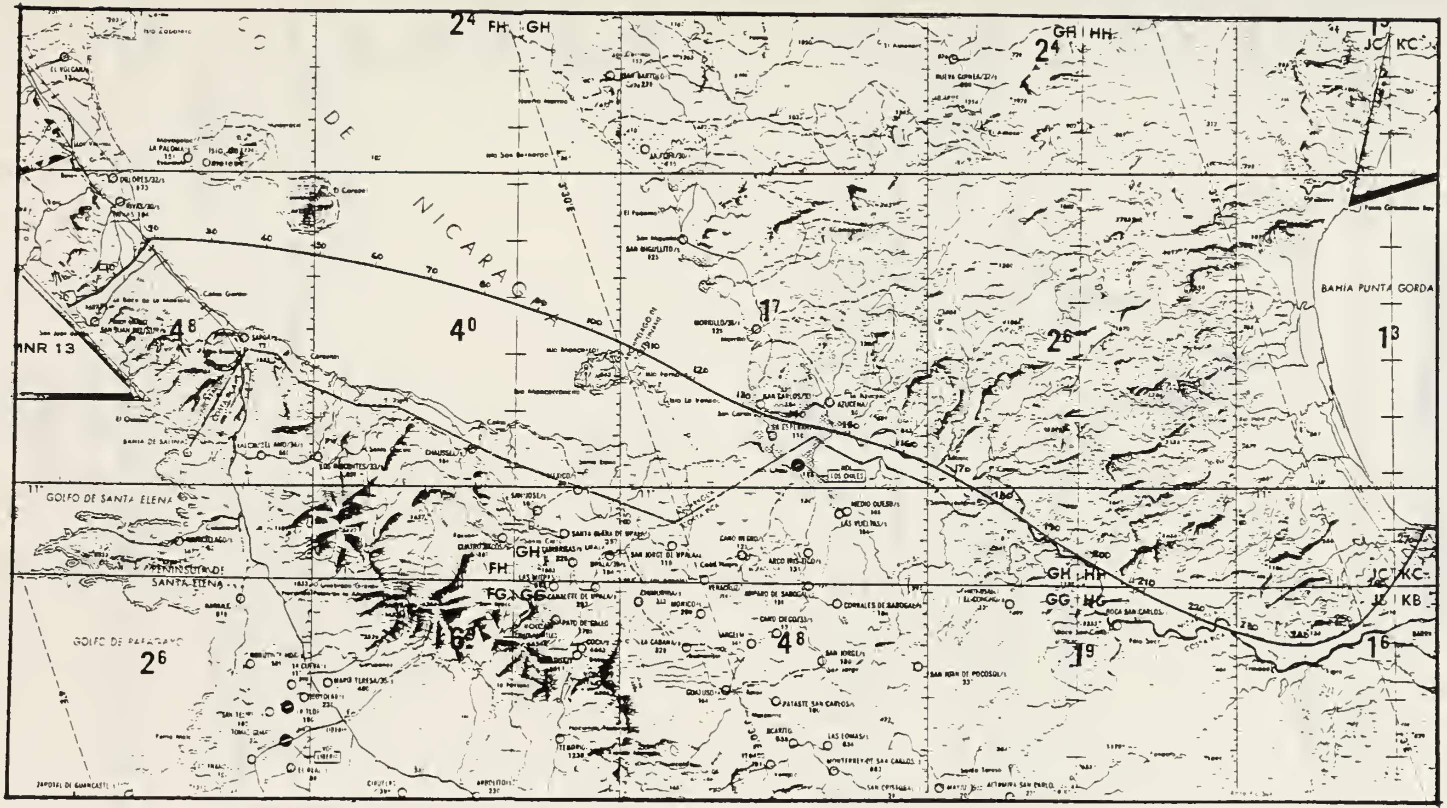
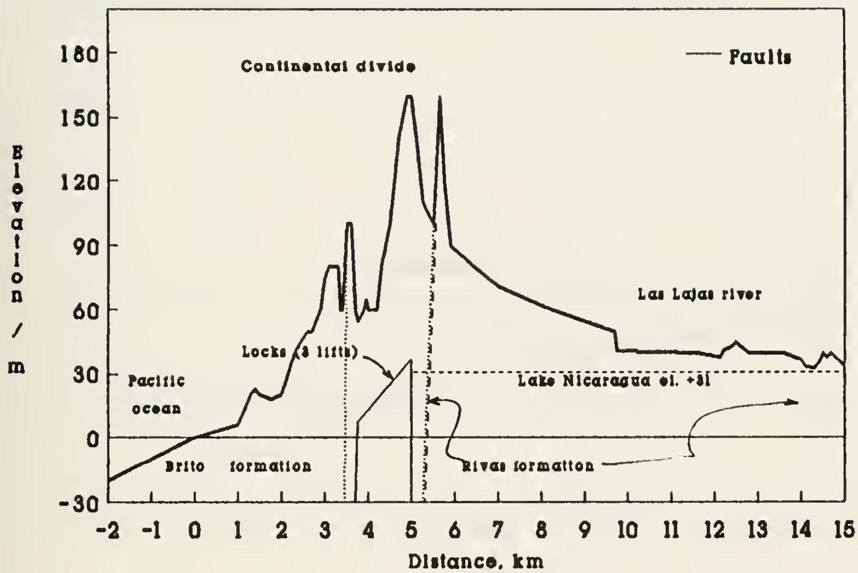


Fig. 12 Nicaragua route

Nicaragua profile



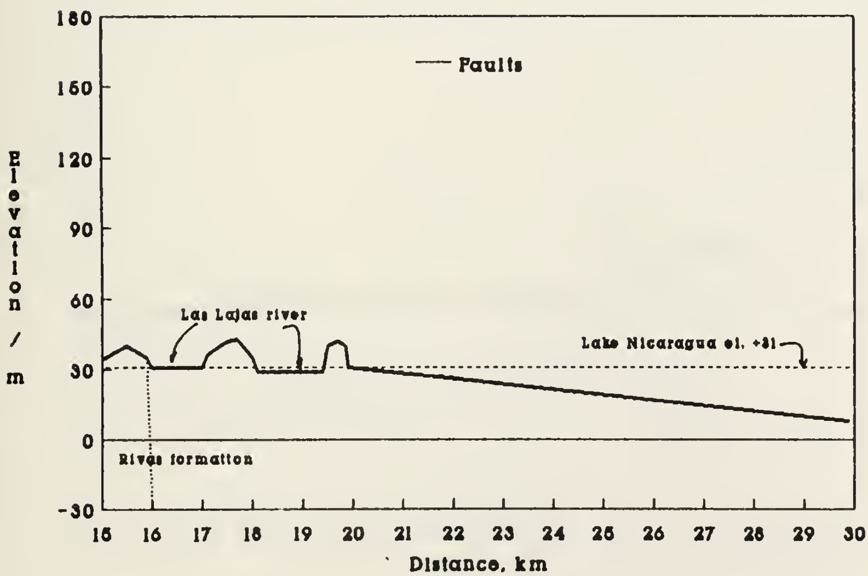
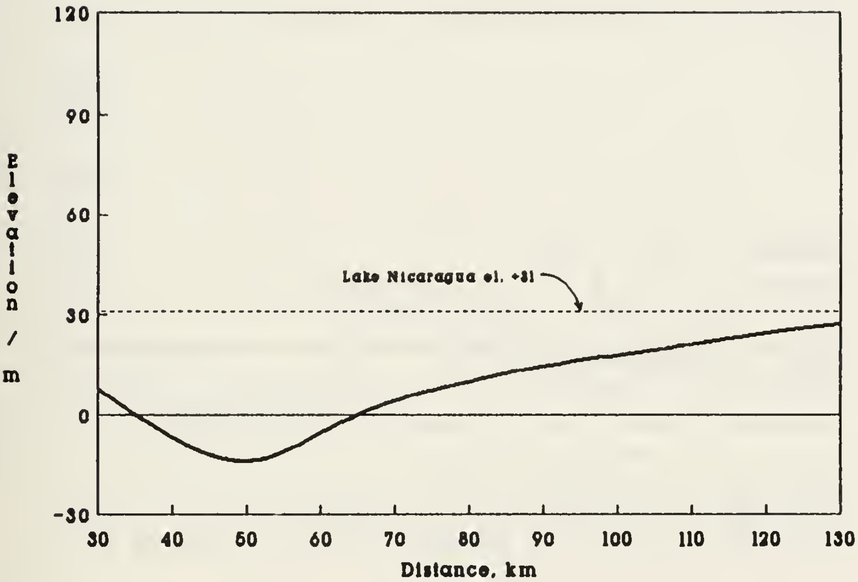


Fig. 13

Nicaragua profile



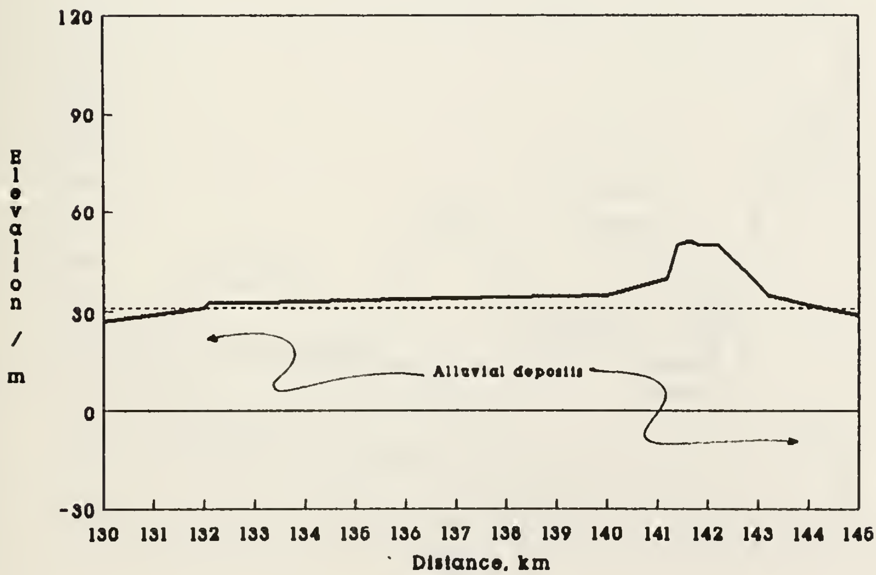
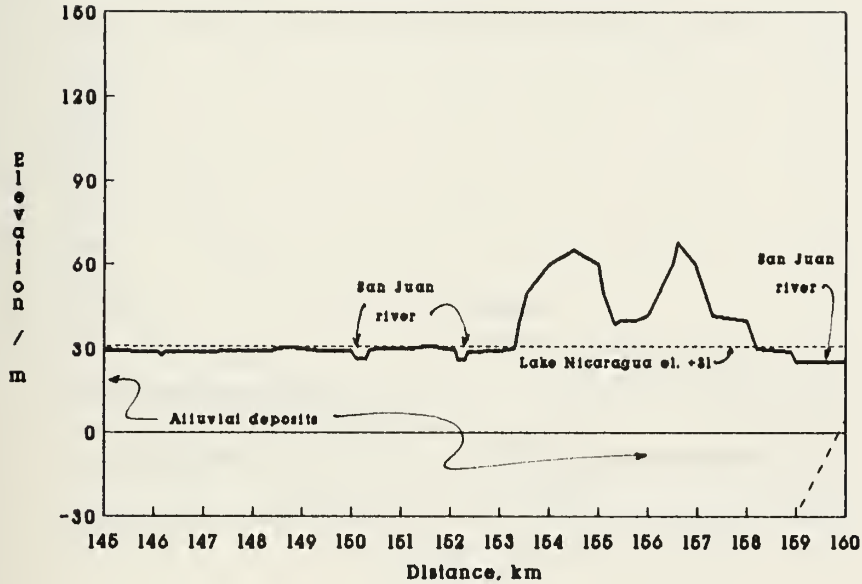


Fig. 14

Nicaragua profile



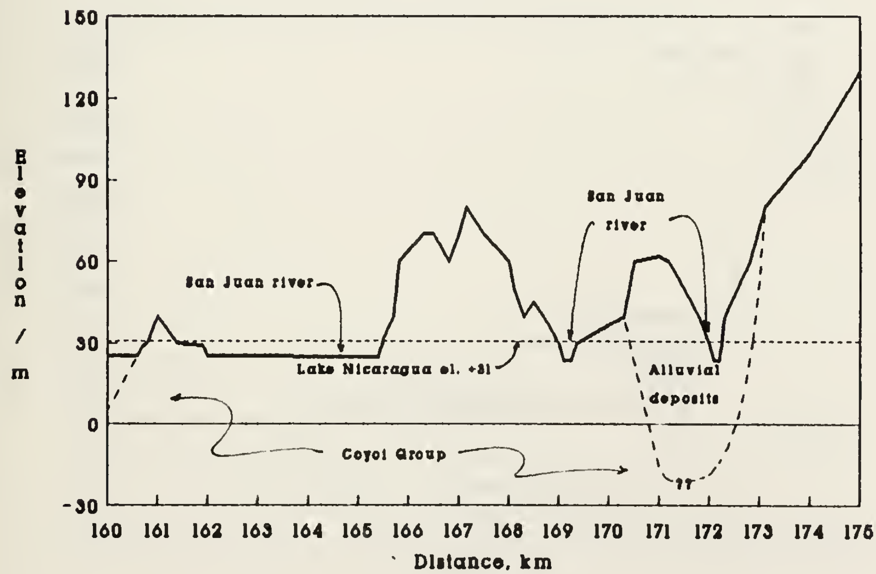


Fig. 15

Nicaragua profile

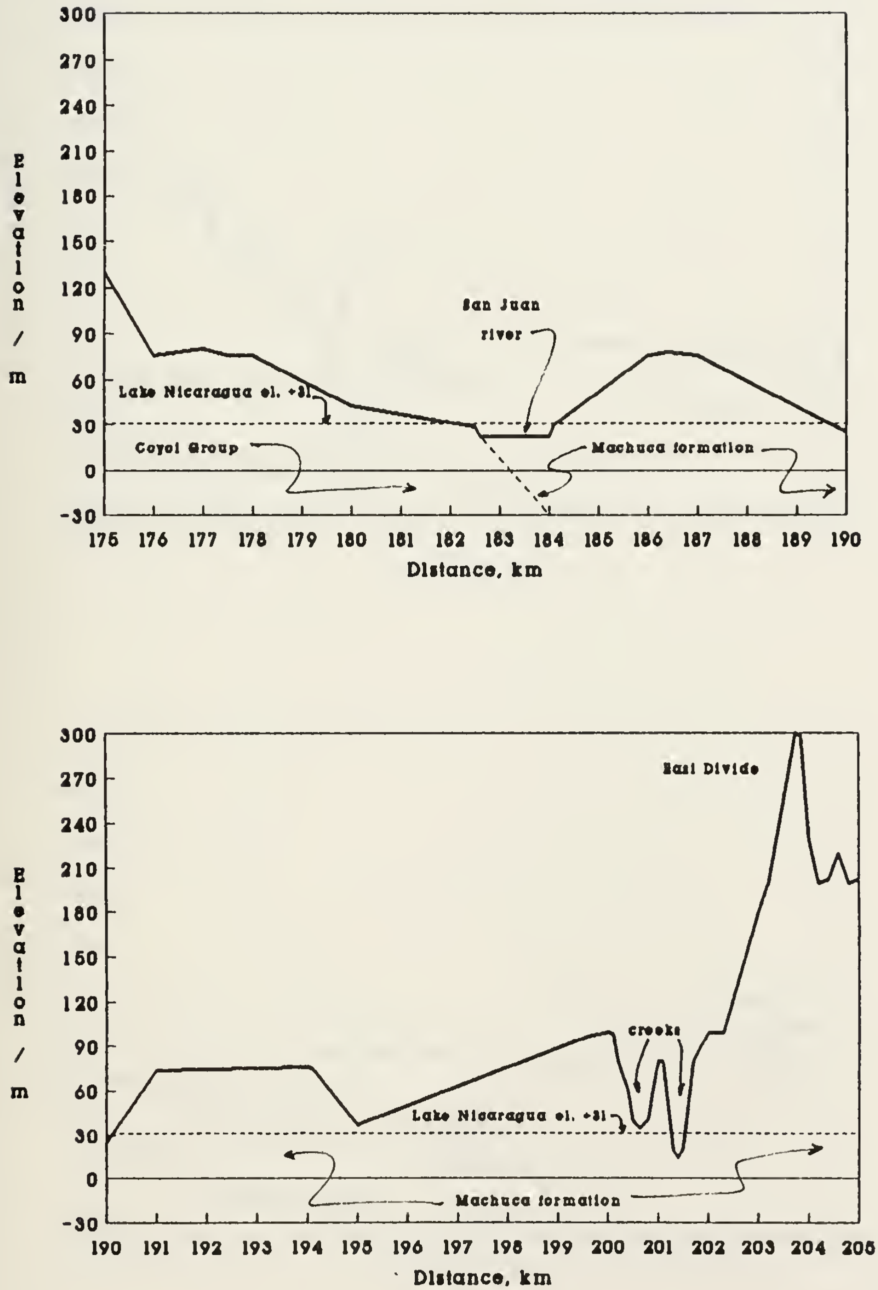


Fig. 16

Nicaragua profile

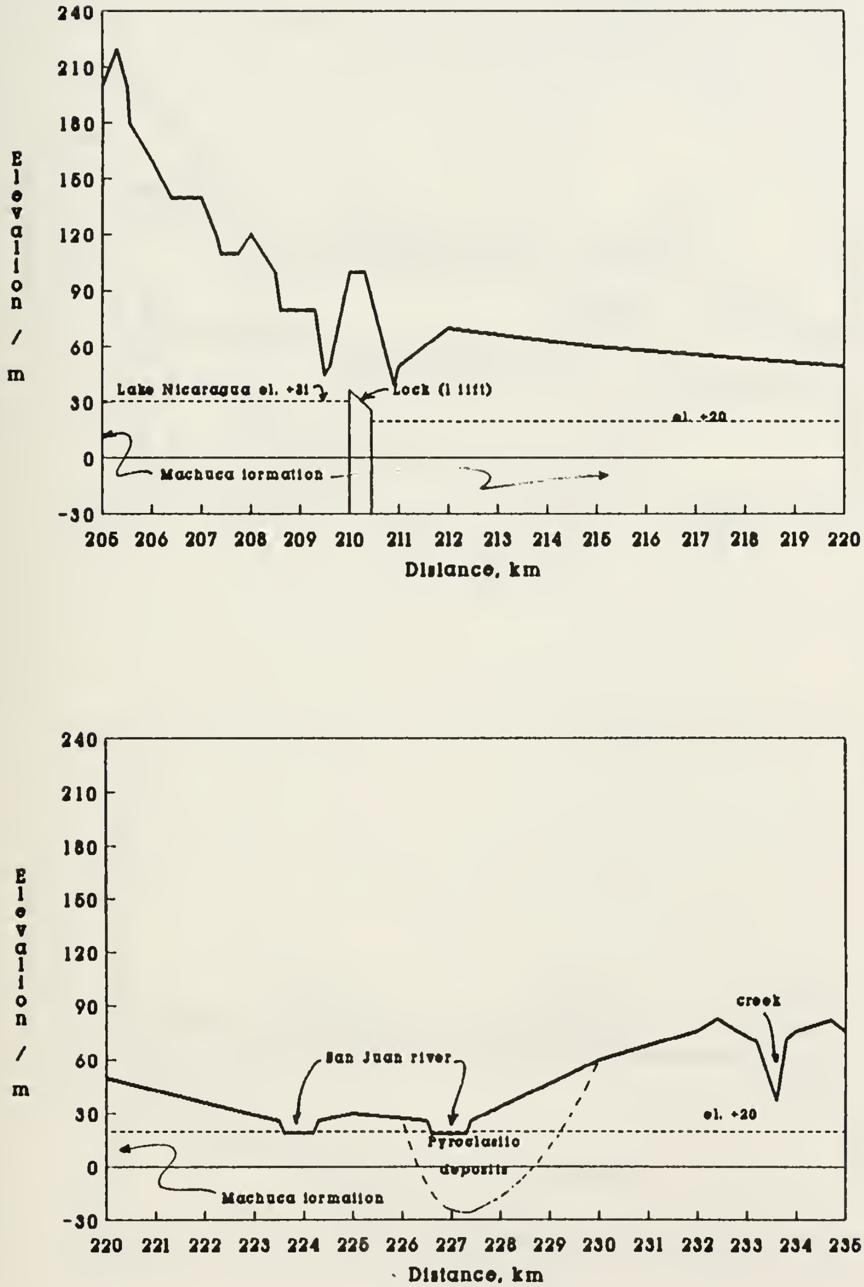


Fig. 17

Nicaragua profile

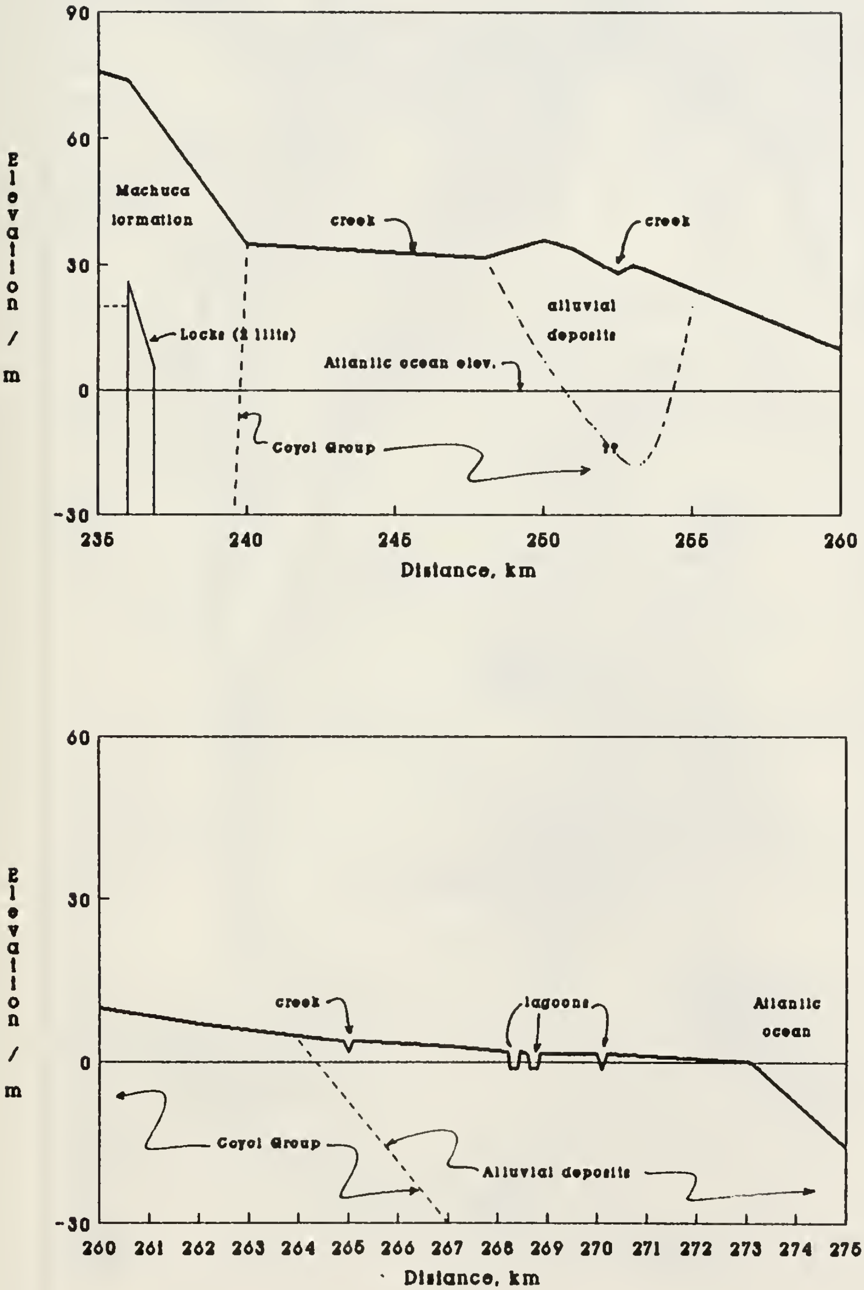


Fig. 18

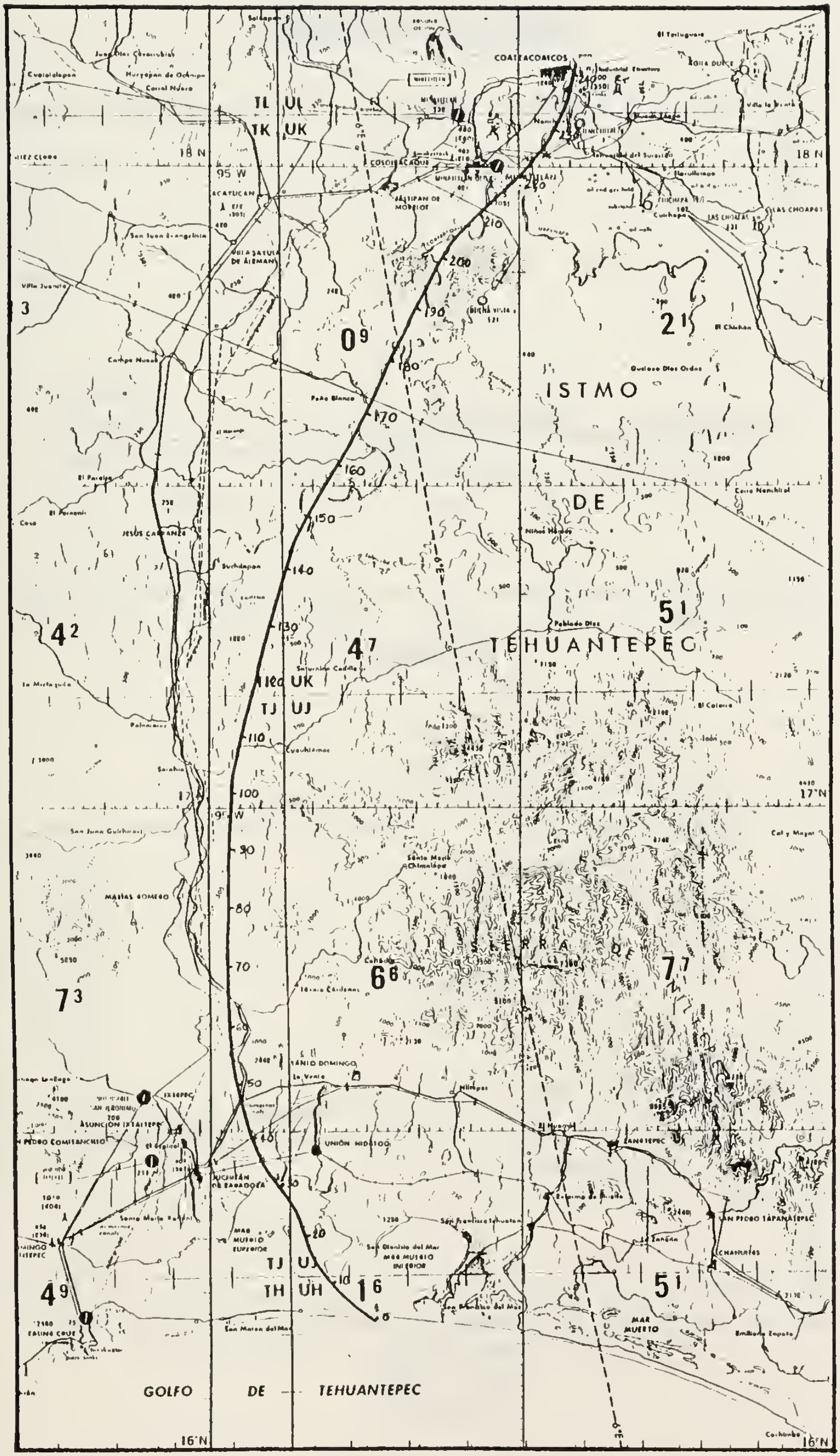
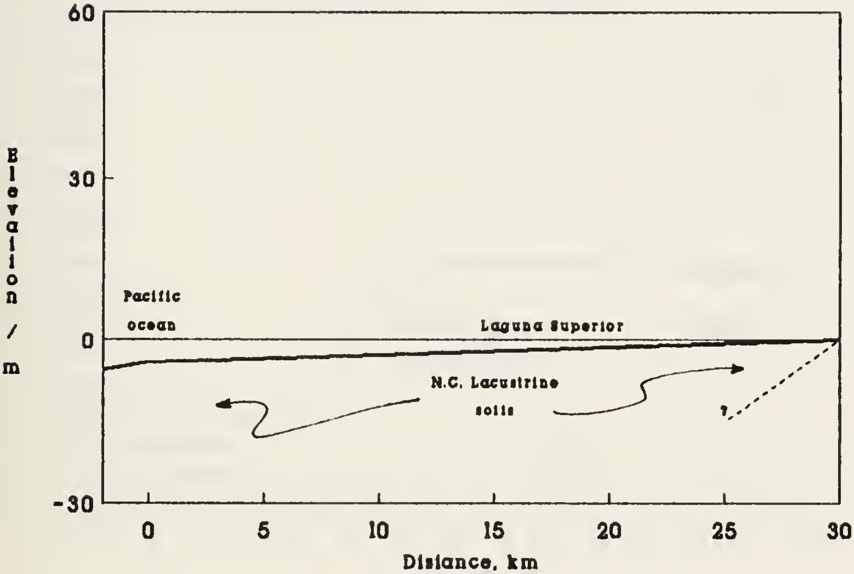


Fig. 19 Mexico route

Mexico profile



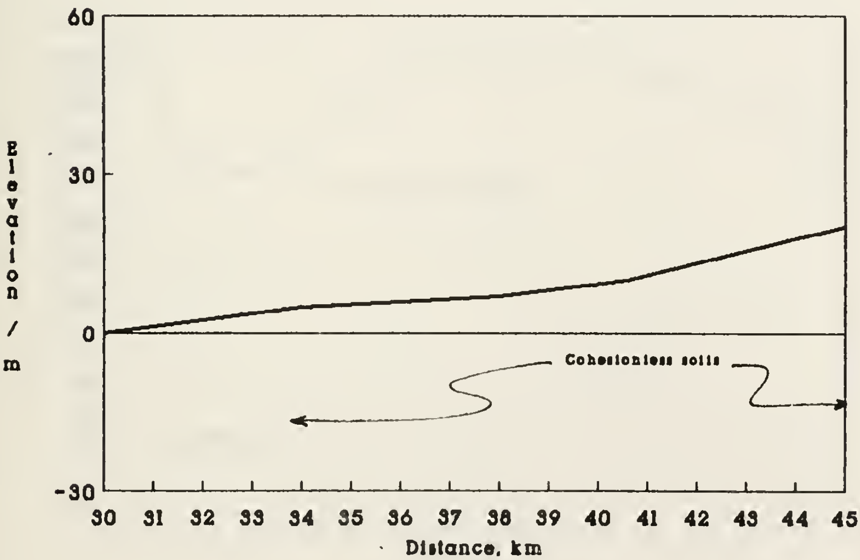


Fig. 20

Mexico profile

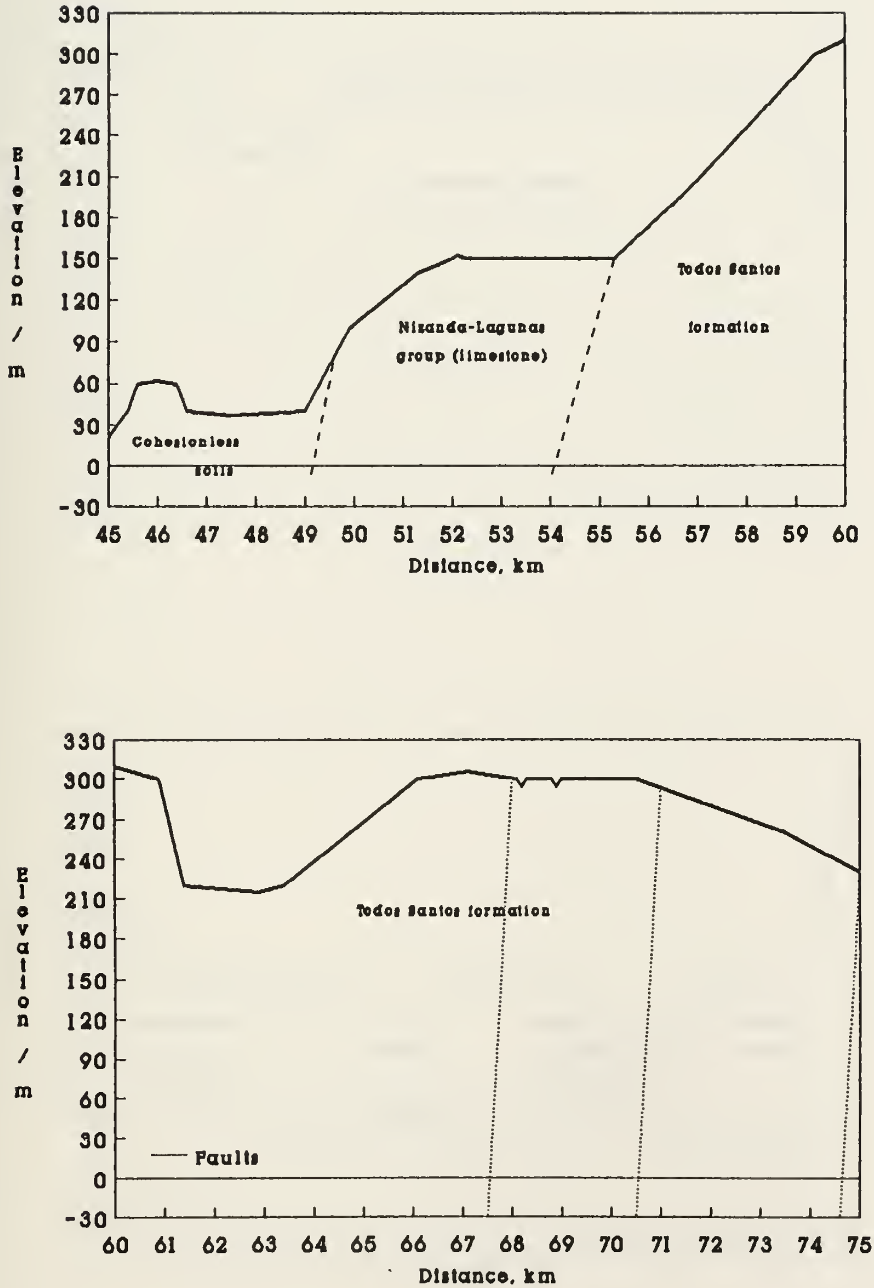
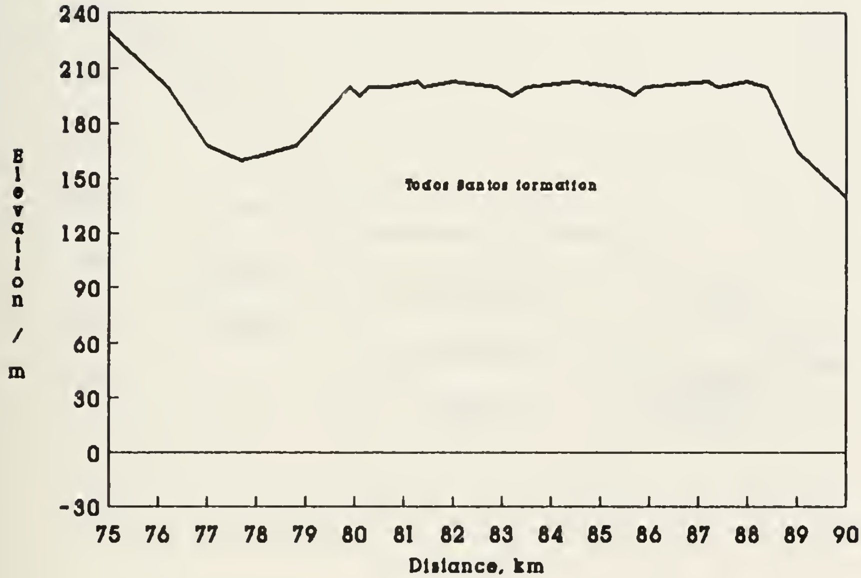


Fig. 21

Mexico profile



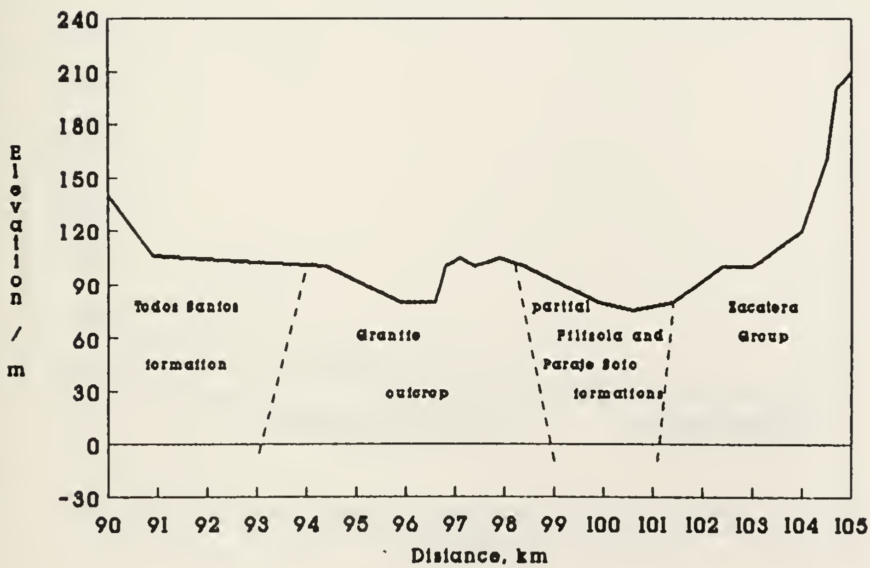
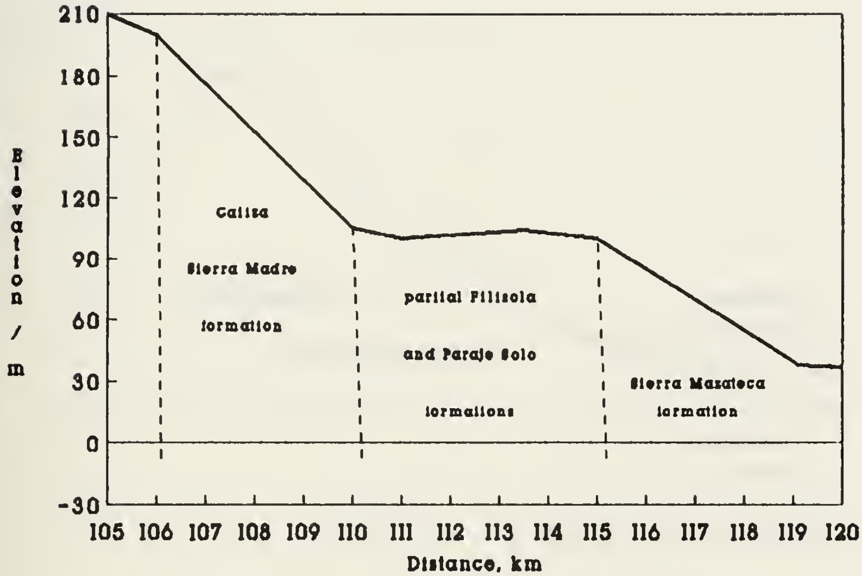


Fig. 22

Mexico profile



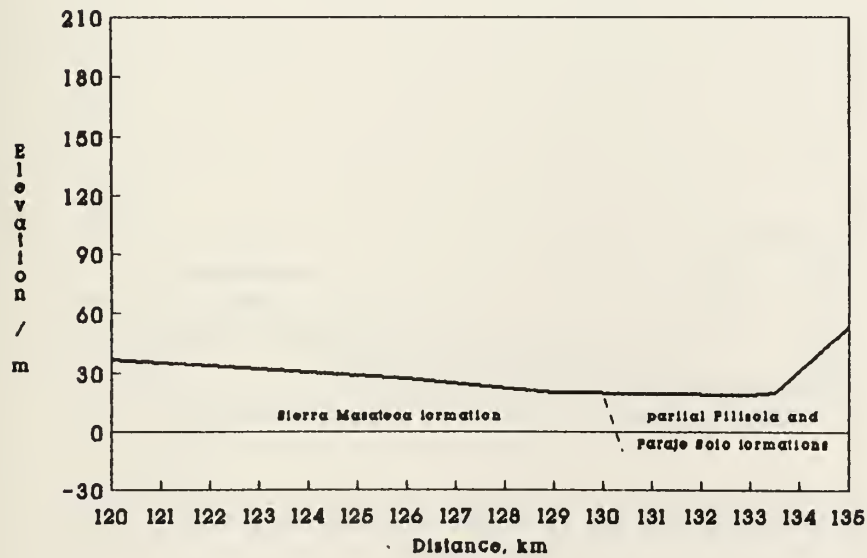
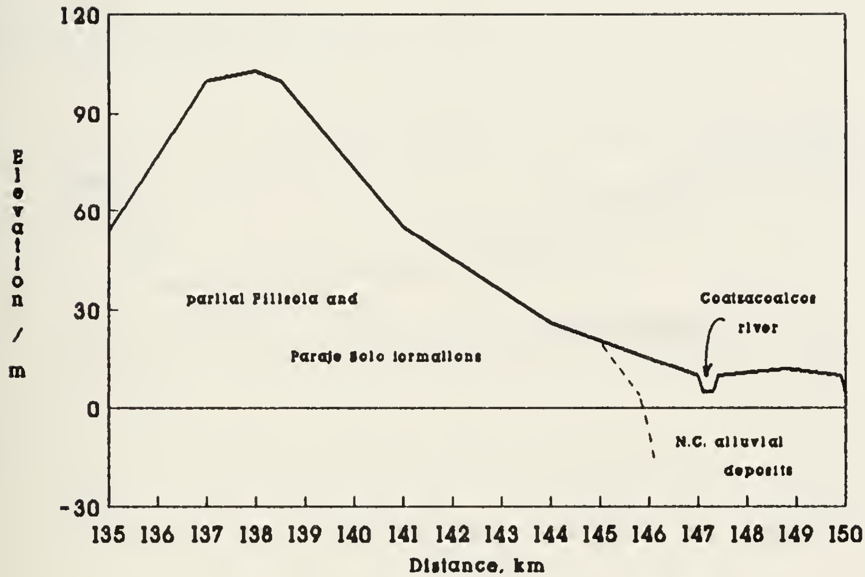


Fig. 23

Mexico profile



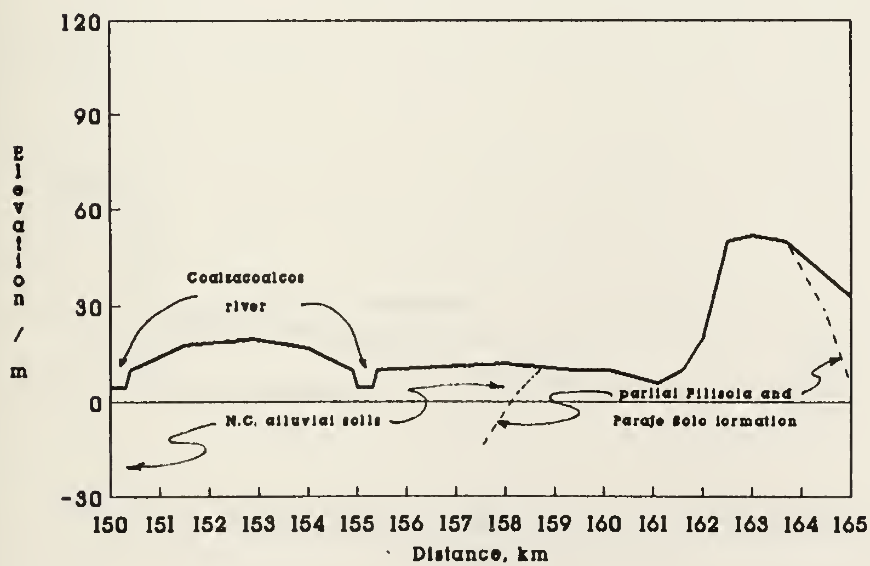
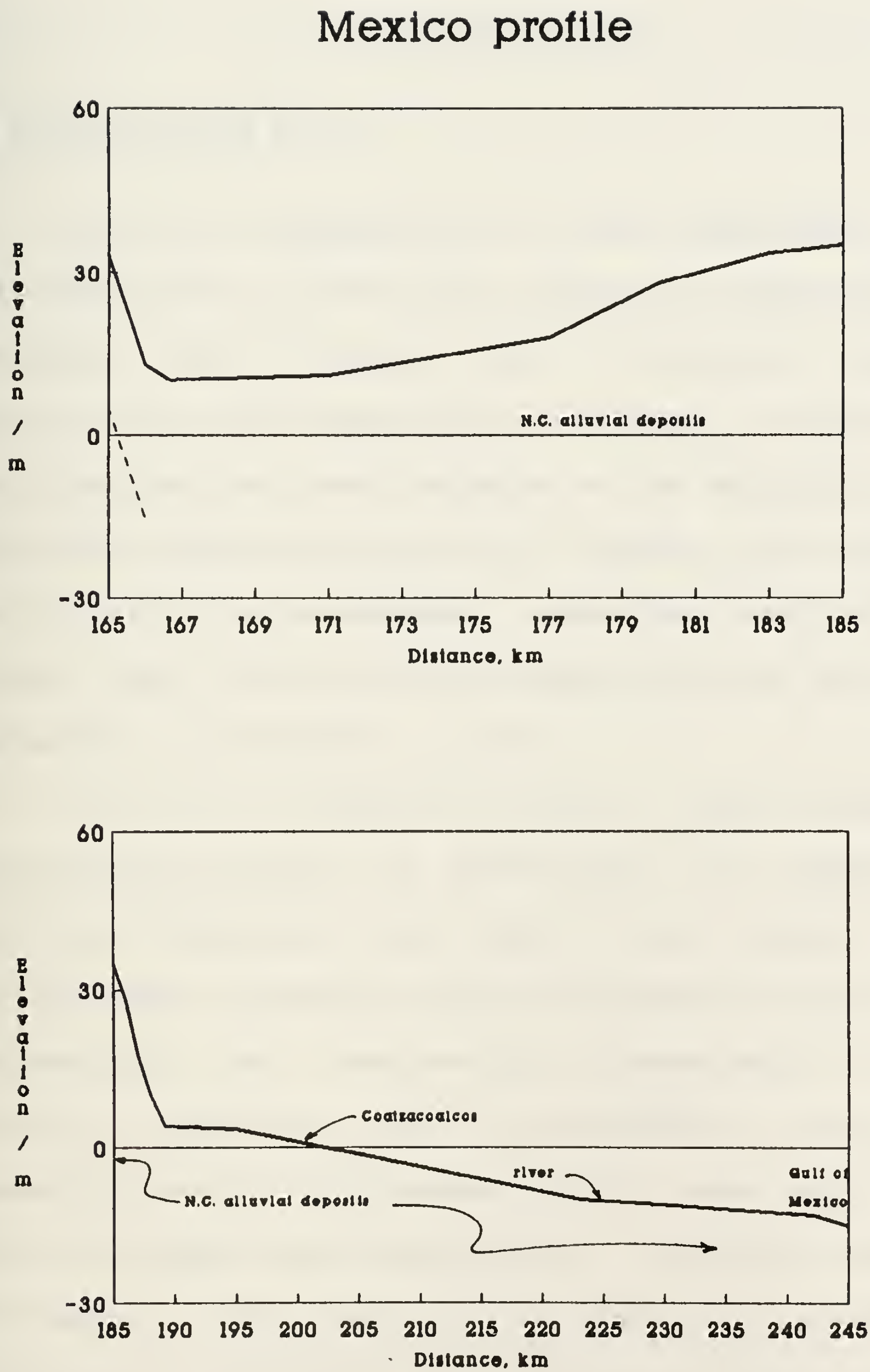


Fig. 24



Mexico profile
60
30
0
-30
Elevation / m
N.C. alluvial deposits
165
167
169
171
173
175
177
179
181
183
185
Distance, km
60
30
0
-30
Elevation / m
Coatzacoalcos
river
Gulf of
Mexico
N.C. alluvial deposits
185
190
195
200
205
210
215
220
225
230
235
240
245
Distance, km

Fig. 25

TOPOGRAPHY

INTRODUCTION

After an examination of the subsurface it is only befitting to offer the reader an opportunity to evaluate other features that invariably affect a project of such magnitude as the one at hand. In this section, salient features of the natural ground, important man-made additions, climate and vegetation cover will be discussed, stressing the principal events and dwelling into minute details only when necessary to elucidate a point.

It will be noticed that in some cases the referenced material is admittedly old. However, it must be remembered that some of the areas through which these alternate routes traverse are not easily accessible, and engineering researchers, having little incentive to investigate since the construction of the Panama canal, have made scant efforts to go into these areas. Therefore, use will be made of some information from the walk-through surveys of the early days of canal route debates. These were the results of expeditions that were

conducted to gather data for technical reasons or to back-up the presentations of the different supporters of any one route.

Having dispensed the preliminaries, I find it appropriate to proceed with a discussion of the three routes.

COLOMBIA

Beginning on the Pacific side, the alignment enters through the Curiche river, a small river which drains a narrow coastal plain and the foot hills west of the continental divide. Upon crossing the continental divide, which reaches a height of about 275 m on this particular route, the alignment follows a tributary to the Atrato river, the Truando river. The portion of the alignment up to about kilometer 55 crosses through an area of dense vegetation cover with very limited population. The region is largely underdeveloped and therefore minimal manmade features will be encountered; although, a limited amount of agricultural and lumbering operations are carried on in the area (Atlantic-Pacific Interoceanic Canal Study Commission, 1970). The climate is tropical

and the area experiences annual rates of precipitation in excess of 2500 mm (100 in.); considering these conditions, the jungle can be expected to be very apt to overtake any parcel left unattended.

From kilometer 55 to the end of the alignment the scenery undergoes a complete change. The swamps of the Atrato river cover a widely extended area subject to flooding and with considerable vegetation. The first thorough exploration of the Atrato region was undertaken in 1852 by John C. Trautwine, one of the chief engineers of the Panama Railroad; he found the marshy overflowed banks of the Atrato completely uncultivated and uninhabited as far as its confluence with the Sucio river, 61 miles from the sea (Mack, 1944). In his summary Trautwine reports that from near its mouths up to near its source, the river flows between natural levees, or raised banks, which at ordinary stages of water, protect the adjacent country from overflow; these levees are gradually formed by the river itself, which every time it overflows them, raises them still higher, by the deposition of an additional thin layer of mud; the

largest trees are seen on the levees and the cultivation of the soil, whenever practiced, is restricted within the limits of the tops of the levees (Trautwine, 1852). In his account, Trautwine notes the width of the Atrato to vary from 250 to 400 yards up to the Sucio river confluence, about 80 km upstream from the sea, which is also the point he reports sighting the first houses; one interesting fact is that he reports seeing not one rock on the Atrato, from its mouth up to its very source. Except for the additional developments that have sprouted along the natural levees of the Atrato, Trautwine's account coincides with the state of affairs in the Atrato swamps today; a modern aerial photograph of the Rio Sucio hamlet shows the houses concentrated in a 70 to 80 ft wide strip parallel to the shoreline. An up-to-date map of the region shows two additional hamlets downstream from Rio Sucio, which apparently are the only incursions by man between the sea and Rio Sucio since Trautwine's report.

The nature of the swamp is such that it has prevented the completion of the Panamerican highway, leaving a gap that spans the width of the swamp on

the Colombian side and the breadth of the mountains that form the Continental divide on the Panamanian side.

There appears to be no improvements, other than the hamlets mentioned above, throughout the alignment of this route rendering almost virgin terrain for any undertaking. This could be seen as an advantage from the point of view that the enterprise will not affect any populous settlements and, on the contrary, will help develop the region. On the other hand, a disadvantage could be perceived in the fact that the immense logistical support required for this endeavor would have to be brought into the area and mobilized from great distances over unimproved or nonexistent roads.

NICARAGUA

The Pacific littoral in the vicinity of the starting point of the alignment is dotted with a myriad of promontories and small semicircular bays carved by the capricious erosion of the ocean into the relatively soft sedimentary rock formations that form the nearby hills and end almost abruptly along

the shoreline. The foot hills west of the continental divide and formed by the Brito formation offer a rough topography with extensive sandstone outcrops close to the shores and a deciduous forest upland. May to October marks the rainy season with the remainder of the year very dry and hot (Incer, 1973). On the east side of the continental divide, gentler slopes are encountered characterized by semiarid plains that reach the lake. The alignment runs parallel to National Road 16 from San Juan del Sur to the lake shore, with an average separation of 3 km in between. The area has several small settlements scattered throughout and the alignment crosses an old winding road bed three times along the way.

The route along the lake has two features worth mentioning; the volcanoes of Ometepe island which have already been mentioned earlier and the presence of sharks, rays and tarpons in the lake, a sign of its ancestral connection to the sea. The height of the volcanoes on Ometepe island are 1556 m and 1326 m for the Concepcion and Maderas respectively.

The route enters land again at San Carlos on the southeastern side of the lake. Incer (op. cit.) reports a population of approximately 9700 for the year 1971. The climate starts to change from here to the Atlantic; at San Carlos, Incer (op. cit.) describes it as having some three months (February to April) with no rain but the remaining rainy months maintain the dense vegetation green with an average annual rain of 3000 mm (118 in.); the climatological conditions in this region are described as monsoonal jungle.

Past San Carlos, the banks of the San Juan river are dotted with small settlements of which the largest ones are San Juan del Norte, on the Atlantic coast, and El Castillo; the latter one is located at about kilometer 175 of the alignment and is the site of an old Spanish fort whose remnants still exist. The width of the river between San Carlos, on the lake, and El Castillo, can reach 300 m and has wide curves crossing low lying lands subject to inundation; (Incer, 1973). At El Castillo, and downstream, there are some rapids and at about kilometer 200, the mountains of the East Divide allow

the river a narrow passage; dense jungle covers the mountains and the climatological conditions are described as tropical pluvious jungle with hot and rainy weather year round (Incer, 1973). The jungle is characterized by a continuous tree forest that forms a vast canopy about 40m above ground where only wide leafed vegetation that can survive in the penumbra grows (Incer, 1973). This forest represents an important source of timber for any project in the area.

Closer to the Atlantic end and past the mountains of the East Divide, which can reach heights of over 300 m, a coastal plain develops; the alignment crosses a swampy area with lagoons of various sizes formed by the alluvial deposits. In 1860 San Juan del Norte had a good harbor, and steamers could go easily up the river to the wharves; then the San Juan river broke its banks about 20 miles upstream, and changed its main current into the Colorado, into Costa Rican territory, and, there being no washout by the San Juan current, the sea rolled the sand up across its mouth until a high bank was made that one could walk on; San Juan del Norte

was no longer on a river, but on a lake (Sheldon, 1899). This process has probably repeated itself in the course of time creating the various lagoons and small canals that indent this area throughout the last 15 km of the alignment. The town of San Juan del Norte is the last settlement on the alignment and was the center of operations for the ill-fated interoceanic canal construction started here in 1889. The bulk of the construction effort was a breakwater to protect the harbor of San Juan del Norte; dredging out portions of the silted lagoon; building of warehouses, machine shops, and a wharf equipped with steam cranes; establishment of a settlement about two miles from San Juan del Norte and erection of offices, hospitals and living quarters; building of telegraph and telephone lines from San Juan del Norte to El Castillo; blasting of a section of the Machuca rapids to facilitate steamboat navigation; dredging of a channel inland from San Juan del Norte 1.5 miles long for the canal itself; construction of 11.5 miles of railroad parallel to the canal line; and importation of locomotives and freight cars (Mack, 1944). How much of this remains is unknown but Incer

(1973) reports the existence of an abandoned dredge in the bay at San Juan del Norte.

MEXICO

An unusual topographical characteristic marks the beginning of this route on the Pacific ocean. Its initial leg of approximately 30 km is through a lagoon connected to the ocean by an opening in a long sandbar. Cutting across the lagoon, the route enters land at a point east of the town of Juchitan de Zaragoza located on a coastal plain with a windy and dusty rainless season for six months out of the year. The part of the coastal plain where the alignment enters is a dry, parched tract covered with cactus and thorny low bushes (Covarrubias, 1946). The map depicts numerous small canals in this area on the borders of the Laguna Superior; these canals appear to be a means of mining the abundant supply of common salt found on the isthmus. The alignment crosses over the railroad tracks running between the towns of Juchitan de Zaragoza and Union Hidalgo; also it crosses the road between Juchitan de Zaragoza and Matias Romero at two points as they compete for the

passage of least elevation through the hills that form the continental divide. The alignment passes about 7 km east of the town of Matias Romero. At this point there is a sudden change in the landscape from the arid plains of the Pacific to the luscious, dark green jungle (Covarrubias, 1946). The next stretch of the route, up to the vicinity of Minatitlan, is through the basin of the Coatzacoalcos river consisting of depopulated jungle except for a few Indian villages, and oil and lumber camps; the region is dotted with rolling hills, fertile upland valleys and cool tablelands growing to the east into the wild, unexplored Chimalapa mountains (Covarrubias, 1946); despite the date ascribed to this statement, it appears that this is the current situation in the Coatzacoalcos river basin. Gonzalez Reyna (op. cit.) also states that the Chimalapa mountains east of the isthmus, are depopulated and little known due to the lack of roads necessary for penetration. A recent map fails to show any towns or settlements in the surroundings of the Coatzacoalcos river. Only past the city of Minatitlan does the map show any settlements; in the area between Minatitlan

and the port city of Coatzacoalcos, there is a conflict between the proposed route and an underground pipeline that connects the refineries across the isthmus. Also, the alignment crosses the various roads heading east from both of these cities. Extensive manmade facilities that exist in the industrial complex of these cities would interfere adversely with the construction of an interoceanic canal. Therefore, requiring their relocation.

SUMMARY

The preliminary character of this report cannot be overemphasized, and one of its aims is to provide insight to the available information that could serve as an initial part of a far reaching project to construct a second interoceanic canal. The three routes considered have been the subject of scrutiny by many others, people of different professions and interests, who have expressed their opinion in relation to feasibility, operational advantage and/or efficiency. It is felt that the question of construction feasibility needs to be re-examined in light of the significant advances the field of geotechnical engineering has gone through since the building of the Panama Canal, which has served as a model to formulate judgement of similar projects. Unfortunately, the failure of private enterprise to materialize any canal project at Colombia, Panama, Nicaragua or Mexico, as evidenced by the plethora of lapsed concessions in the literature, relegated this type of project to a government.

Perhaps it is time to revisit those old sites objectively, armed with the quickly fading experience

obtained over the years at Panama, but also, more importantly, with the newly developed knowledge in the geotechnical field.

It must be clear to the reader that it was neither intended nor desired to reach a final opinion on a preferred route, out of the three presented in this report; reaching such a conclusion based on the given information is simply not prudent. Rather, it is hoped this work serves to make evident the lack of current, usable information that would enable a conscientious determination of the best route. Therefore, if after reading this unpretentious work you conclude that in fact the database is scattered, decrepit, disorganized and unretrievable, except through great efforts, then this work has served its purpose. It is felt that the next time the question of where is the optimum location for an interoceanic canal comes up, the answer will be as elusive as ever.

Notwithstanding the above assertions, it is felt that after examining the three routes with some detail, an opinion should be offered as to the most advantageous of the alternatives and why. A concise

statement should suffice because, as mentioned earlier, Panama appears to have the most economical and feasible sea-level alternative for a second canal. If, on the other hand, the political climate is such that Panama is excluded, I believe that Colombia offers the most advantages despite the remoteness of the area. It has the shortest distance and a single high point; minimal, if any, effect on populated areas; approximately 2.6 billions of cubic yards of the excavation is in rock compared with 3.4 and 6.5 for Nicaragua and Mexico respectively; it is the closest route to Panama, thereby allowing for expeditious technical support; and finally, because of the swamp, future expansion is feasible at lower cost than the other two routes.

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VITA

Samuel Jose Peña was born in Puerto Plata, Dominican Republic, on March 8, 1951, the son of Angel M. Peña Rivas and Luz Maria Vergez de Peña. In 1968, he completed his high school studies at the Don Bosco School in Santo Domingo, Dominican Republic. Starting in 1970, during the evenings, he attended Polytechnic Institute of Brooklyn, then The City College of New York until 1976. He graduated in June 1977 with a B.S.C.E. from the University of Miami. Upon graduation, he worked as a design engineer for various firms in the Miami area and in February 1981, he entered the Civil Engineer Corps of the U.S. Navy with the rank of Lieutenant (Junior Grade).

In June of 1989, he entered the Graduate School of the University of Texas at Austin under the auspices of the U.S. Navy.

Mr. Peña is a registered Professional Engineer in Texas. He shares his home with his wife and three children.

Permanent address: 21 S. W. 109 Ave.
Miami, Florida 33174

This thesis was typed by Samuel Jose Peña.

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Thesis
P3287 Peña
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